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**Regional Geochemical Reconnaissance
of Archean
Metavolcanic-Metasedimentary Belts
in the
Pukaskwa Region**

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ABSTRACT

During the summer of 1968, a regional geochemical reconnaissance combined with geological mapping at a scale of 1 inch to 1 mile (Operation Pukaskwa) was carried out over an area of 1,200 square miles (3,100 km²) on the north shore of Lake Superior between Wawa and Marathon. Three hundred and sixty square miles (930 km²) of the map-area is underlain by Archean metavolcanics and metasediments, most of which are contained within two, generally, synclinal belts separated by intervening granitic terrain. The northern belt, named the "Kabenung Lake Belt" (Bennett and Thurston 1972), forms the western end of the much larger Michipicoten metavolcanic-metasedimentary belt. It varies in width from 3 to 8 miles (5 to 16 km) and trends west-southwest from Kabenung Lake for a distance of 30 miles (48 km). The southern belt, named the "Mishibishu Lake Belt", forms an arc, convex to the north, averaging 10 miles (16 km) in width and extending over a length of 35 miles (56 km) from the University River on the shore of Lake Superior, through Mishibishu Lake and westward to the mouth of the Pukaskwa River.

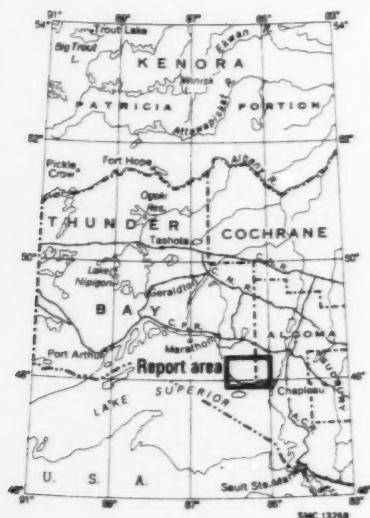


Figure 1 - Key map showing location of the Pukaskwa area. Scale 1 inch to 200 miles (1:12,672,000).

The relative areal abundances of major volcanic and sedimentary units in the Kabenung Lake Belt (with corresponding figures for the Mishibishu Lake Belt following in brackets) are: mafic metavolcanics and related mafic intrusions 70 percent (64 percent); felsic metavolcanics and related intrusions 1 percent (10 percent); greywacke, siltstone, argillite, and iron formation 23 percent (24 percent); conglomerate and arkose 6 percent (2 percent) (Bennett and Thurston 1972).

The stratigraphy of the two metavolcanic-metasedimentary belts is essentially similar, although the Mishibishu Lake Belt is more structurally complex. The oldest rocks are dominantly subaqueous basaltic flows and equivalent gabbroic sills with subordinate intercalated flows and pyroclastics of andesite, dacite, and sodic rhyolite composition. Chemical data and normative mineral compositions derived from 50 total rock analyses indicate the existence of both tholeiitic and calc-alkalic compositions

in the subalkaline Archean volcanic belts of the Pukaskwa region and confirm the widely recognized association of tholeiitic basalts with calc-alkalic andesite-dacite-rhyolite successions in Archean "greenstone" belts of the Precambrian Shield (Irvine and Baragar 1971). The Pukaskwa volcanic rocks reflect the general pattern of chemical uniformity, low alkali content (particularly K_2O), low TiO_2 content, and limited range in Al_2O_3 that is present in widespread Archean volcanic sequences. Average trace metal abundances estimated from analyses of 121 samples of Archean volcanic rocks are (in ppm): Ni 117, Cu 73, Zn 95, Co 37, and Mn 1300.

The metavolcanics are overlain by thick sequences of metasedimentary strata consisting mainly of greywacke, argillite, siltstone, arkose, and quartzite with substantial low grade deposits of Algoma-type oxide, sulphide and carbonate facies iron formation. Distinctive and more or less continuous units of polymictic conglomerate form recognizable marker horizons at the top of the metasedimentary assemblage in both belts. The average trace metal abundances derived from 63 samples of Archean metasediments are (in ppm): Ni 67, Cu 44, Zn 75, Co 23, and Mn 815.

Approximately 68 percent of the map-area is underlain by granitic plutonic rocks that intrude the Archean metavolcanic-metasedimentary belts and occupy extensive areas surrounding them. The discrete syenite-monzonite-quartz monzonite plutons that intrude older metavolcanics and metasediments at Kabenung Lake and Mishibishu Lake are, on the average, lower in SiO_2 and higher in combined alkalis than the extensive masses of granodiorite, quartz diorite, quartz monzonite, and trondhjemite that surround the "greenstone" belts. Limited total rock analyses (27 samples) appear to indicate the existence of significantly different Na_2O/K_2O ratios in two major granitic blocks surrounding the Kabenung Lake and Mishibishu Lake Belts. Average trace metal abundances in 104 samples of granitic rocks are (in ppm): Ni 23, Cu 13, Zn 50, Co 18, and Mn 322.

Reconnaissance stream sediment geochemistry in parts of the Pukaskwa and University River Basins has contributed to a rapid preliminary evaluation of the base metal potential of the two major Archean metavolcanic-metasedimentary belts and has further clarified the role of certain independent variables (i.e., distributions of bedrock types and Pleistocene surficial deposits, sparsely mineralized rocks, surface Eh-pH environments and metal absorbing manganese-iron hydroxides) in controlling regional geochemical dispersion patterns in areas of continental glaciation.

Fast flowing streams and rivers, within 5 to 10 miles (8 to 16 km) of the Lake Superior shore, drain a region of moderate relief covered by a thin till sheet and have steep gradients suitable for significant mechanical transport. Reconnaissance stream sediment geochemistry can be applied in this area with results similar to those observed in glaciated regions of the northern Appalachians. However, a temporary halt in the withdrawal of the Wisconsin ice sheet, approximately 18 miles (30 km) north of Lake Superior, is marked by an irregular east-west band of outwash sand and gravel that modifies significantly the regional geochemical response to underlying metavolcanics and metasediments. Regional patterns of Cu, Zn, and Ni distribution in bedrock and in stream sediments illustrate the association of low metal background in drainage sediments with areas of thick outwash cover.

Anomalously high concentrations of cold citrate soluble total heavy metals and HNO_3-HCl soluble Cu, Zn, Ni, and Co have been outlined at several locations within the map-area by analysing the unground -80 mesh (177 micron) fraction of stream and spring sediment samples collected at intervals of 1,500 feet (450 m). Drainage sediments entering Lake Superior between Point Isacore and the mouth of the University River have anomalously high contents of all metals tested. Detailed stream sediment geochemistry, soil geochemistry and E.M. surveys have been successfully used in follow-up exploration to locate drill targets.

REGIONAL GEOCHEMICAL RECONNAISSANCE OF ARCHEAN METAVOLCANIC-METASEDIMENTARY BELTS IN THE PUKASKWA AREA

By

W.J. Wolfe¹

INTRODUCTION

Location and Access

The Pukaskwa region is located on the north shore of Lake Superior between Wawa and Marathon, south and west of Highway 17. The area discussed in this report occupies about 1,200 square miles (3,100 km²) extending from Lake Superior to Latitude 48°20' and bounded to the east and west by Longitudes 85°00' and 86°00'. Highway 17 passes through the northeastern corner of the map-area, and a power transmission line of the Ontario Hydro-Electric Power Commission extends northwestward across the area from about Latitude 48°03' at the eastern edge of the map (Figure 2) to about Longitude 85°39' on the northern edge of the map. Much of the northeast corner of the map-area is made accessible by gravel roads connecting the power transmission line with Highway 17 near Kabenung Lake (see Bennett and Thurston 1972). A winter road extends along most of the length of the power line.

South and southwest of Iron Lake, the major rivers are fast flowing, boulder filled and unsuitable for extended canoe travel. Coastal sections of the map-area can be reached by boat from Michipicoten Harbour, about 15 miles (25 km) east of the map-area. Lakes of suitable size for use of fixed-wing aircraft are not numerous and, large tracts of topographically rugged terrain can only be reached by helicopter-supported foot traverses.

Scope and Purpose of the Geochemical Survey

The Operation Pukaskwa geochemistry project was mainly conceived for the purpose of collecting basic geochemical exploration data to be used for a regional evaluation of base metal potential in the two relatively unexplored Archean metavolcanic-metasedimentary belts that occur in the Pukaskwa region. Analysis of the trace metal content of stream sediments has proven to be a useful guide to unexposed bedrock ore in unexplored terrain (Hawkes *et al.* 1957), and large-scale regional programs of chemical analysis of systematically collected samples of stream sediment

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have been extensively used to broadly outline areas of anomalously high heavy metal content. Their results assist in the selection of specific areas for staking and detailed geochemical and geophysical exploration (Boyle *et al.* 1958, 1966; Smith 1960; Gleeson 1967; Wolfe, Mason and Mazerolle 1967; Wolfe and Szabo 1968; Austria 1970, 1971).

Regional geochemical surveys have been successfully applied to tropical and savannah terrains of high geochemical relief where the modern weathering regime is predominantly chemical, and direct relationships can be established between the bedrock chemistry and the composition of overlying residual soils and derived alluvial sediments (Garrett and Nichol 1967). In Canada, the broad-scale, low-relief geochemical patterns obtained by chemical analysis of drainage sediments are predominantly a reflection of clastic geochemical patterns supplemented by weak, recently re-established hydromorphic geochemical anomalies in Pleistocene glacial cover. Modern soils and alluvial sediments are derived mainly from unconsolidated Pleistocene deposits that have been mechanically mixed and transported by relatively recent glacial, glaciofluvial and glaciolacustrine processes. In spite of the difficulties introduced by variable topographic and climatic conditions superimposed on complexly distributed glacial features, reconnaissance stream sediment geochemistry is still regarded as the best and most widely used regional geochemical exploration technique in Canada.

Regional surveys of drainage geochemistry have been most frequently used in predominantly valley-glaciated areas of the Yukon, British Columbia and the Maritime Provinces where in a reconnaissance sense, samples may be treated as of relatively local derivation. Although not always definitive for the location of individual mineral deposits, systematic sampling and analysis of stream sediments at the reconnaissance level will very adequately outline mineralized belts and regional geological features in regions of continental glaciation such as the Precambrian Shield (Bradshaw, Clews and Walker 1971). The application of stream sediment reconnaissance in economically attractive regions of the Superior Province has been limited mainly by widespread, poorly drained muskeg terrain unsuitable for significant alluvial transport, and by extensive areas of complex glacial stratigraphy capped by thick deposits of post-glacial lacustrine material. In the absence of these restrictions, regional stream sediment reconnaissance can be usefully applied to areas like the Pukaskwa district, where fast flowing streams and rivers with gradients suitable for significant mechanical transport drain a region of moderate relief covered by a simple, thin till sheet.

Samples of active sediment were routinely collected from the channels of streams draining a 360 square mile (930 km²) area underlain by Archean metavolcanics, metasediments and associated intrusions. The unground -80 mesh (177 micron) sieve fraction of dried sediment samples was used for the determination of cold citrate soluble total heavy metals and hot HNO₃-HCl extractable Cu, Zn, Ni, Co, and Mn. The results obtained were then compared with similar trace element data obtained by analyzing systematically collected specimens of bedrock. This was done to evaluate the effects of bedrock chemistry and glacially transported overburden on the regional distribution of metal background in alluvial sediments. These data combined with field observations were used to examine the influence

of surface Eh-pH conditions, metal absorbing manganese-iron hydroxides, and other factors in the secondary environment that obscure the relationship between metals in stream sediments and the bedrock geology.

Acknowledgments

The writer was assisted in the collection, preparation, and field colorimetric analysis of geochemical samples by G.R. Wright, P.J. Wojdak and D.J. Herdman. Much of the background information contained in this report concerning the geology and mineral deposits of the area is directly attributable to G. Bennett and P.C. Thurston, members of the geological staff of the Ontario Division of Mines. The author would like to thank the personnel of Pegasus Airlifts Limited for their co-operation in transporting field crews under conditions of difficult terrain and less than ideal weather. A large part of the original statistical evaluation of the stream sediment data was undertaken by G.R. Wright in the preparation of an undergraduate thesis at the University of Toronto (Wright 1969). Excepting the field colorimetric determinations of cold citrate-soluble total heavy metals, all chemical analyses were performed by the staff of the Mineral Research Branch of the Ontario Division of Mines.

PHYSICAL FEATURES

The Pukaskwa district lies on the north side of the Lake Superior Basin within the Abitibi Upland Province (GSC Map 1254A) of the Canadian Shield. In general, the Precambrian Shield is a bedrock surface of low to moderate relief 1,300 to 1,700 feet (390 to 510 m) above sea level. Near the Lake Superior shoreline much of the upland surface lies at about 1,500 feet (450 m) elevation, and broad areas to the south of Mishibishu Lake have summits at 1,700 to 1,800 feet (510 to 540 m). Tip Top Mountain (elevation 2,120 feet (650 m), located just to the northwest of the map-area, 7 miles (11 km) from Lake Superior, is the highest point in Ontario. The major rivers gather volume in the uplands region and descend abruptly to the present Lake Superior shoreline at 602 feet (185 m) above sea level. The lower 10 to 20 miles (16 to 32 km) of the Pukaskwa, East Pukaskwa and University Rivers occupy deeply incised valleys commonly 400 to 600 feet (120 to 180 m) deep. Local relief is generally less extreme in the northern half of the map-area where extensive deposits of thick Pleistocene outwash cover parts of the Kabenung Lake metavolcanic-metasedimentary belt.

The run-off water of the map-area flows south and southwest into Lake Superior through the drainage basins of the University, Pukaskwa and East Pukaskwa Rivers. Drainage follows a largely bedrock controlled, trellis-type pattern, except over the areas of thick glacial outwash deposits, where a modified dendritic drainage pattern has developed. Within 12 to 15 miles (20 to 25 km) of the Lake Superior shoreline, the average straight line gradients of the Pukaskwa and University Rivers are approximately 45 feet per mile (8.5 m per km).

Bare bedrock hill tops are draped by thin deposits of non-stratified, poorly sorted glacial drift. Typical well differentiated podzolic soils are

developed on freely drained till and outwash sand under a coniferous to mixed forest cover of black spruce, white spruce, balsam fir, jack pine, trembling aspen and white birch. Jack pine are abundant in areas of thinly covered bedrock and well-drained sandy soil, and aspen and birch species occur mainly on well-drained hillside slopes. Widespread black spruce are particularly dominant in intervening valleys and poorly-drained peat and muskeg environments. The climate is cool to temperate with a mean annual precipitation of 32 inches (80 cm). Unfortunately, rainfall during the summer of 1968 deviated markedly from the 30-year normal.

TABLE 1 | RAINFALL DATA AT WHITE RIVER, ONTARIO, FOR SUMMER MONTHS OF 1968 COMPARED WITH 30-YEAR NORMAL VALUES.

	1968 Rainfall (Inches)	30-Year Normal Based on Period 1931-1960
June	6.90	3.11
July	9.82	2.82
August	1.90	2.88
Total for Period	18.62	8.81

Atmospheric Environment Service-Department of the Environment-Canada figures (Table 1) show that the rainfall at White River (20 miles; 32 km, north of the map-area) in June, 1968 was over twice the average, and that in July over three times the average for the 30-year normal based on the period 1931-1960. On several occasions, the stream sediment sampling program was halted during periods of unusually high run-off volume caused by heavy rainfall. The chemistry of stream waters tends to be influenced appreciably by rainfall and seasonal dilution. In comparison, stream sediments are as a rule more chemically stable and less subject to trace element variability caused by fluctuations in run-off volume. Nevertheless, no quantitative estimates can be given for the effects of abnormally high run-off in the major river basins during June and July on the regional metal content of sediment samples.

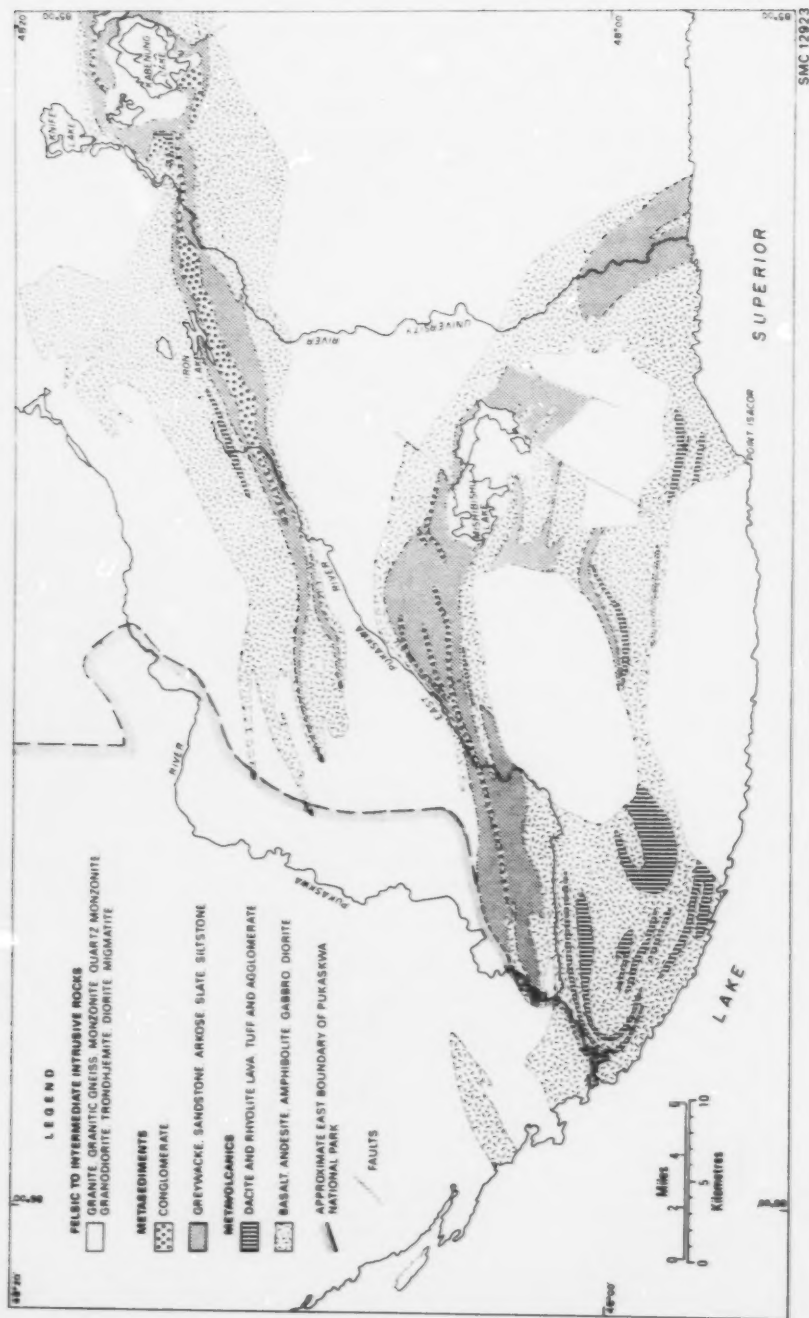
GENERAL GEOLOGY

The geology of the Pukaskwa region is fully described by Bennett and Thurston (1972), and the general geological summary that follows is intended only to provide a background for presentation of the geochemical data. Ontario Division of Mines Preliminary Geological Maps P.506 and P.507 (Bennett *et al.* 1969a, b) and Open File Report 5073 (Bennett and Thurston 1972) should be examined for additional information concerning the geology and mineral deposits of the Operation Pukaskwa map-area.

Archean metavolcanics and metasediments underlie about 360 square miles (930 km²) or approximately 30 percent of the 1,200 square miles (3,100 km²) bounded by Lake Superior, Latitude 48°20' and Longitudes 85°00' and 86°00'. Figure 2 illustrates the regional geology of the Pukaskwa District, and geological age relationships are summarized in the Table of Lithologic Units (Table 2). Two important belts of Archean metavolcanics and metasediments form east-west trending synclines separated by extensive

TABLE 2 | **TABLE OF LITHOLOGIC UNITS FOR THE PUKASKWA AREA**

CENOZOIC	
RECENT	
	Swamp and stream deposits
PLEISTOCENE	
	Till, sand and gravel
<i>UNCONFORMITY</i>	
PRECAMBRIAN	
PROTEROZOIC	
KEWEENAWAN	
	Basalt, rhyolite
<i>UNCONFORMITY</i>	
	Diabase, olivine diabase
<i>INTRUSIVE CONTACT</i>	
PROTEROZOIC OR ARCHEAN	
	Diabase, quartz diabase
<i>INTRUSIVE CONTACT</i>	
ARCHEAN	
INTERMEDIATE TO FELSIC INTRUSIVE ROCKS	
KABENUNG LAKE STOCK AND MISHIBISHU LAKE STOCK	
	Porphyritic Syenite and monzonite, porphyritic pyroxene monzonite, porphyritic quartz monzonite, porphyritic quartz-bearing monzonite
<i>INTRUSIVE CONTACT (ASSUMED)</i>	
	Biotite quartz monzonite, biotite trondhjemite, hornblende trondhjemite, hornblende quartz monzonite, porphyritic granite, hybrid granite, migmatite, pegmatitic muscovite granite
METASEDIMENTS	
	Polymictic conglomerate, greywacke, arkose, siltstone, slate, graphitic slate, sandstone, iron formation and ferruginous sandstone.
INTERMEDIATE TO FELSIC METAVOLCANICS AND ASSOCIATED INTRUSIVE ROCKS	
	Dacite to rhyolite flows, intermediate to felsic tuff and volcanic breccia, intermediate to felsic agglomerate, porphyritic dacite (intrusive)
MAFIC TO INTERMEDIATE METAVOLCANICS AND ASSOCIATED INTRUSIVE ROCKS	
	Basalt, andesite, amygdaloidal basalt, pillow basalt, porphyritic basalt, gneissic amphibolite, amphibolite, chlorite schist, chlorite-biotite schist, gabbro, porphyritic gabbro, diorite



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Figure 2 - Regional geology of the Pukaskwa area.

granitic terrain and intruded by late granitic plutons. The northern belt, named the "Kabenung Lake Belt" (Bennett and Thurston 1972) forms the western end of the much larger Michipicoten metavolcanic-metasedimentary belt. It trends WSW from Kabenung Lake for a distance of about 30 miles (50 km) and is an eastward-plunging synclinorium, 3 to 8 miles (5 to 13 km) wide, which is refolded around the Kabenung Lake pluton. The southern belt, named the Mishibishu Lake Belt, forms an arc, convex to the north, averaging 10 miles (16 km) in width and extending over a length of 35 miles (56 km) from the University River on the shore of Lake Superior, through Mishibishu Lake and westward to the mouth of the Pukaskwa River. The stratigraphy of the two metavolcanic-metasedimentary belts is essentially similar, although the Mishibishu Lake Belt is more structurally complex.

The oldest rocks are tightly folded Archean mafic metavolcanic flows of predominantly basaltic composition. These rocks consist mainly of massive and pillow lavas with coeval coarser-grained early gabbroic intrusions. The general absence of mafic pyroclastic rocks and the widespread development of flow breccias, pillow breccias and pillow structures are features consistent with subaqueous basaltic extrusion. Middle greenschist facies regional metamorphism is prevalent, and the mafic volcanic rocks consist mainly of albite, epidote, chlorite, pale-green to blue-green amphibole and accessory quartz, carbonate, sphene, iron-titanium oxides and zircon. Near the margins of the Archean belts, where later granitic batholiths have raised the metamorphic grade to amphibolite facies, the mafic metavolcanics are recrystallized to medium-grained gneissic amphibolites. Volcanic rocks are locally metamorphosed within the hornblende-hornfels facies of thermal metamorphism in areas adjacent to late monzonite-syenite plutons that intrude the metavolcanic-metasedimentary assemblages at Kabenung Lake and Mishibishu Lake.

The mafic metavolcanic flows are intercalated with thin, discontinuous units of andesite, dacite and sodic rhyolite flows and pyroclastics. Although extensive centers of felsic volcanism occur east of the map-area in the Wawa-Goudreau-Renabie sections of the Michipicoten Belt, the estimated abundance of felsic metavolcanics in the Kabenung Lake Belt is only about 1 to 4 percent of the total metavolcanic-metasedimentary assemblage (Table 3). The thickest sections of felsic metavolcanics occur near the top of the volcanic sequence west of Iron Lake and in the nose of an anticline about 1 mile (1.6 km) west of Kabenung Lake. These units are mainly composed of quartz-feldspar porphyry flows and related pyroclastics of dacite to quartz latite composition.

Metavolcanic sequences in the north and east sections of the Mishibishu Lake Belt are dominated by basaltic flows and pillow-lavas. Intermediate and felsic metavolcanics probably comprise less than 2 percent of the total volcanic assemblage in these areas. In comparison, these metavolcanics are widely distributed in the western end of the Mishibishu Lake Belt where low angle dips associated with an open, westward-plunging anticlinal structure may exaggerate estimates of true abundance based on areal distribution. Most of the felsic metavolcanics located at the western end of the Mishibishu Lake Belt between Lake Superior and the Lower East Pukaskwa River are massive feldspar porphyry and feldspar-hornblende porphyry flow rocks with very subordinate pyroclastics. Intermediate to felsic volcanic breccia,

Geochemical Reconnaissance Pukaskwa

TABLE 3 | AREAL ABUNDANCE OF MAJOR ROCK UNITS IN THE KABENUNG LAKE AND MISHIBISHU LAKE "GREENSTONE" BELTS. BASED ON PLANIMETER SURVEYS OF ODM PRELIMINARY MAPS P.506 AND P.507 (AFTER BENNETT AND THURSTON 1972).

	<i>Rock Type</i>	<i>Area (Miles)²</i>	<i>Area (Km)²</i>	<i>Percent of total less granitic rocks</i>
KABENUNG LAKE BELT	Mafic metavolcanics and early mafic intrusions	105.0	272.0	70
	Felsic metavolcanics	1.6	4.1	1
	Greywacke, slate, I.F.	34.9	90.4	23
	Conglomerate	8.7	22.5	6
	Kabenung Lake Stock	9.8	25.4	-
	Total area less late intrusions	160.0	414.4	-
MISHIBISHU LAKE BELT	Mafic metavolcanics and early mafic intrusions	139.0	360.0	64
	Felsic to intermediate metavolcanics	22.5	58.3	10
	Greywacke, slate, I.F.	54.3	140.6	24
	Conglomerate	3.6	9.3	2
	Mishibishu Stock	9.6	24.9	-
	Total area less late intrusions	229.0	593.1	-

bedded tuff, and lapilli-tuff are more abundant in the south-central part of the belt between Point Isacor and Mishibishu Lake.

The metavolcanics are overlain by thick sequences of metasedimentary strata consisting of greywacke, argillite, siltstone, slate, iron formation, conglomerate, arkose, chert and quartzite. The metasediments occupy the central synclinal core of the Archean belts, forming about 29 percent of the total metavolcanic-metasedimentary assemblage in the Kabenung Lake Belt and about 26 percent of the total assemblage in the Mishibishu Lake Belt. About 12,000 feet (3,600 m) of metasediments with minor mafic metavolcanics are exposed along the shore of Lake Superior at the eastern end of the Mishibishu Lake Belt, and minimum thicknesses of 6,000 to 8,000 feet (1,800 to 2,400 m) are present in the western half of the same belt. Thickness estimates for sections of metasedimentary strata in the Kabenung Lake Belt range from 3,000 to 8,000 feet (900 to 2,400 m) (Goodwin 1964; Bennett and Thurston 1972).

Greywacke, siltstone and slate form rare interflow beds within the main metavolcanic sections but are extensively interbedded with volcanic flows near the boundaries of the major metasedimentary belts. The main

metasedimentary sequences contain well-bedded greywacke-siltstone sections that commonly include individual beds showing graded grain size variations suitable for stratigraphic top determinations. Synclinal axes lie within persistent zones of polymictic conglomerate and interbedded arkose located at or near the top of the major metasedimentary sections. A conglomerate horizon, up to 2,000 feet (600 m) thick, occurs along the axis of the Iron Lake Syncline, and related zones of interbedded conglomerate and arkose form units up to 4 miles (6 km) long and 500 to 3,000 feet (150 to 900 m) thick in sections of metasediments surrounding Kabenung Lake. The conglomerates are generally poorly bedded and commonly interfingered with greywacke-arkose lenses of highly variable thickness and limited strike length. In the Mishibishu Lake Belt, a thin but persistent unit of conglomerate and arkose west of Mishibishu Lake can be traced continuously along strike over a distance of 12 miles (20 km). Except in localized areas, where conglomerate clasts are flattened by cross folding near late monzonite-syenite plutons, the conglomerate contains subrounded to well rounded pebbles, cobbles and boulders in a sand-sized arkosic matrix of quartz and feldspar. Fragments of iron formation and mafic metavolcanics are common in conglomeratic units of the Kabenung Lake Belt. Granitic clasts appear to be more abundant in the conglomerates of the Mishibishu Lake Belt (Bennett and Thurston 1972). According to thin section modal analyses by Bennett and Thurston (1972), five granitic cobbles and boulders from conglomerates were classified as albite trondhjemite. The mineralogy of these clasts does not differ substantially from the extensive trondhjemitic batholiths that surround the metavolcanic-metasedimentary belts.

Iron formation is widely distributed in the Michipicoten district of Ontario and occurs within the Pukaskwa region in association with both metavolcanics and metasediments, but constitutes wider and more extensive units in the latter. The most significant deposits of iron formation in the map-area form a more or less continuous unit within a thick sequence of metagreywacke that, with the exception of two major gaps, can be traced for the entire length of the Kabenung Lake Belt. The thickness of this zone varies considerably; the thickest sections occur west of Kabenung Lake (200-400 feet or 60-120 m) and at Iron Lake (200-1,200 feet or 60-360 m). All four facies of Michipicoten-type iron formation have been recognized within the Kabenung Lake Belt. The oxide facies consisting of banded magnetite-hematite and chert is the most abundant facies and probably constitutes about 90 percent of all the iron formation (Bennett and Thurston 1972). The chert layers are pale to dark grey, yellow or jasper red depending on the relative amounts of magnetite and hematite impurities present. The oxide facies locally grades into deeply weathered, limonite-stained sideritic carbonate facies. Locally sulphide-rich sections up to several feet thick are closely associated with chert and carbonate-rich iron formation. The original bedded nature of the thicker pyrite-pyrrhotite zones west of Kabenung Lake has been obscured by widespread intense brecciation during subsequent folding. Minor zones of dark green to greenish brown iron silicates (chlorite, biotite, actinolite, grunerite and stilpnomelane) associated with magnetite and quartz occur within oxide facies iron formation.

In the Mishibishu Lake Belt, an extensive 6 mile (10 km) long zone of greywacke with thin discontinuous interbeds of low-grade iron formation

is located about 5 miles (8 km) southwest of Mishibishu Lake. Iron formation also occurs as discontinuous units interbedded with metavolcanics at the western end of Mishibishu Lake Belt. Two broad zones about 500 feet (150 m) wide extend eastward from the extreme western end of the belt, pass 1 mile (1.6 km) south of the lower East Pukaskwa River, and are truncated by the granitic batholith in the central part of the belt.

Approximately 68 percent of the map-area is underlain by granitic plutonic rocks that intrude the Archean metavolcanic-metasedimentary belts and occupy extensive areas surrounding them. The intervening areas of plutonic-metamorphic terrain contain substantial zones of hornblende-rich migmatite extending westward from the western end of the Kabenung Lake Belt and along the northeastern edge of the Mishibishu Lake Belt. These zones of migmatite and related hybrid, hornblende-bearing granitic rocks are up to 3 miles (5 km) wide, can be traced for 10 miles (16 km) in a westerly direction, and evidently represent partially assimilated extensions of the older "greenstone" belts through younger plutonic terrain.

The individual granitic batholiths are not well defined except where they occur as discrete plutons within the boundaries of the major metavolcanic-metasedimentary belts. For the most part, the batholiths contain oligoclase, microcline, microcline-microperthite and quartz in variable proportions and can be classified as trondhjemite or quartz monzonite. The predominant mafic mineral in uncontaminated plutonic rocks is biotite, generally associated with widespread epidote and chlorite.

Late mesozonal to epizonal intrusions of massive to porphyritic syenite and pyroxene monzonite, quartz-bearing monzonite and quartz monzonite intrude the metasedimentary and metavolcanic assemblages of Kabenung Lake and Mishibishu Lake. Although modified by post-intrusive faulting, the outline of the Kabenung Lake Stock is generally circular in plan with an area of about 10 square miles (26 km²). The Mishibishu Lake Stock is roughly oval in shape with a maximum dimension of 5½ miles (8.8 km) and an area of about 11 square miles (28 km²). These high-level, alkali-rich plutons contain microcline, microcline-microperthite, oligoclase, clinopyroxene, and quartz with accessory carbonates, sphene, zircon, apatite, and iron-titanium oxides. Clinopyroxene is locally replaced by biotite, hornblende or epidote.

All early Precambrian rocks are intruded by post-granite diabase dike swarms that trend N30E, N40W and N-S. These late mafic dikes can be subdivided into quartz-bearing and olivine-bearing tholeiites. Reconnaissance examination of the diabase dikes by Bennett and Thurston (1972) indicated that quartz diabases are predominant in northeast-striking swarms, whereas north-south and northwest-trending dikes are commonly olivine-bearing or olivine-rich. At two locations in the southwestern part of the map-area quartz diabase is intruded by northwest-trending olivine diabase. A northwest-trending diabase dike near Pukaskwa Harbour has been dated at 1030 million years (K-Ar whole rock), (Isotopic Age Map of Canada, Geological Survey of Canada Map 1256A).

Small erosional remnants of Keweenawan lavas rest unconformably on Archean mafic metavolcanics in topographic lows near the shore of Lake Superior. Sections of basalt and amygdaloidal rhyolite up to 30 feet (9 m) thick are exposed in stream valleys located 2 miles (3 km) northeast

of Point Isacor and midway between Point Isacor and the University River. Flow contacts dip south at about 5 to 10 degrees.

PLEISTOCENE GEOLOGY

During the Wisconsin glaciation, the Pukaskwa area was entirely overridden by a fan-shaped advance of continental ice that formed part of a major ice lobe centered to the northeast in the James Bay region. The continental ice flow direction as measured by glacial striae, varies locally within the Pukaskwa map-area between 170° and 225° , but on the average trends 200° . The four most common types of Quaternary deposits are coarse, stony till; glaciofluvial sand and gravel (outwash and esker deposits); deltaic sediments; and beach deposits.

Upland regions along the north side of the Lake Superior Basin are covered by a thin, locally derived sheet of sandy to coarse, stony till. The summits of most hills are devoid of drift cover and except on certain south slopes where till thicknesses may exceed 50 feet (15 m), the till cover is generally less than 20 feet (6 m) thick. The map-area lies beyond the southern limit of younger, fine-grained, highly calcareous till of distant origin that effectively restricts geochemical dispersion by mechanical and chemical processes near ore deposits at Manitouwadge, 55 miles (90 km) north of the Pukaskwa map-area (Garrett 1969). This calcareous clay till was derived from distant sources in Paleozoic terrain of the Hudson Bay Lowlands and was deposited during a late Wisconsin re-advance of the ice front which was halted 30 to 40 miles (50 to 65 km) north of the Pukaskwa region (Grant 1969). The earlier, locally derived stony tills, present over about 70 percent of the Pukaskwa map-area, may be treated, in a regional sense at least, as reflecting the composition of nearby Precambrian bedrock sources.

Small, discontinuous eskers representing the traces of subglacial streams and rivers trend south to south-southwest and are in general restricted to the eastern part of the map-area north of Mishibishu Lake. A temporary halt in the withdrawal of the active Wisconsin ice sheet is marked by a discontinuous east-west-trending system of outwash deposits and meltwater channels extending across the northern half of the map-area and marking the former ice front position approximately 18 miles (30 km) north of Lake Superior. Thick deposits of outwash sand and gravel outlined in Figure 3 are particularly widespread in the northern part of the map-area and for the most part, fill a broad low in the bedrock surface coinciding in a general way with the outline of the Kabenung Lake metavolcanic-metasedimentary belt. The distribution of outwash sediments and meltwater channels shows that runoff from this Pleistocene valley was mainly through the valley of the Pukaskwa River and through streams draining directly south into Lake Superior including a major meltwater channel through the Mishibishu Lake system. Today this valley is drained mainly by the University and East Pukaskwa River systems, whereas the Pukaskwa River drainage basin is shifted more to the northwest.

At about 10,000 years B.P. the Wisconsin ice front lay more or less along the present north shore of Lake Superior and the entire Superior

Basin was occupied by a large continuous preglacial lake known as glacial Lake Minong. This lake produced the highest Pleistocene shoreline features in the northeastern end of the Superior Basin represented in the region of the map-area by beach deposits at elevations of approximately 975 feet (295 m) above sea level, about 375 feet (115 m) above the present level of Lake Superior (Farrand 1960). The level of Lake Minong coincides closely with the top of a large delta formed at the mouth of the Pukaskwa River. Downcutting by the Pukaskwa River through these deltaic sediments has exposed a minimum thickness of 250 feet (75 m) of sediments deposited in Lake Minong at the mouth of the Pukaskwa (Bennett and Thurston 1972). The approximate position of the Minong shoreline and the distribution of deltaic sand and gravel at the mouth of the Pukaskwa are outlined in Figure 3.

The level of Lake Minong fell gradually in discontinuous stages to a minimum established about 8,200 years B.P. and known as glacial Lake Houghton. Post-glacial uplift following the northward retreat of the ice front raised the outlet of the Great Lakes Basin at the head of Lake Nipissing and caused a continuous rise in the level of the Great Lakes forming a single lake known as the Nipissing Great Lakes. In the northeastern end of the Superior Basin, maximum Nipissing levels produced shoreline deposits at elevations of 700 to 710 feet (210 to 213 m) above present sea level about 6,000 years B.P. (Prest 1970, p.730). The approximate Nipissing shoreline outlined in Figure 3 coincides with wave cut cliffs and raised beach deposits near the mouth of the Pukaskwa River.

ECONOMIC GEOLOGY AND MINERAL EXPLORATION

The extensive iron ranges in the eastern end of the Kabenung Lake Belt were discovered and evaluated as early as 1900 during the search for additional high-grade hematite-goethite ores and enriched residual hematite ores of the Michipicoten-type. The major zones of iron formation at Betty Lake, Brotherton Hill, Francis Mine, Iron Lake and Morse Mountain-Mount Raymond are described in detail by Bennett and Thurston (1972). These iron deposits were all sub-ore grade at the turn of the century and although, as a group they form a significant proportion of Ontario's current iron reserves, they cannot be mined economically at present.

Most recently, Algoma Ore Properties Limited (now Algoma Steel Corporation, Algoma Ore Division) explored the Iron Lake range in 1947-1948. The results of a magnetometer survey of the property and the subsequent diamond drilling program apparently did not warrant further expenditure (Bennett and Thurston 1972). In 1953, an airborne magnetometer survey by Algoma Ore Properties Limited over the eastern part of the Kabenung Lake Belt covered most of the major iron deposits in Townships 31 and 32, Range 26 (Files, Regional Geologist's Office, Ontario Ministry of Natural Resources, Sault Ste. Marie). The airborne survey was followed by detailed geological mapping at 1 inch to ¼ mile (1:15,840) scale during 1954 (Goodwin 1964) and by diamond drilling in 1955. The detailed mapping and drilling (8 diamond drill holes totalling 3,153 feet (946 m) and 620 feet (186 m) of Packsack drilling) at the

Geochemical Reconnaissance Pukaskwa

Betty Lake Prospect (Acme Gas and Oil Company Limited) established reserves of 13,420 tons per vertical foot (39,924 t/m) averaging 39.51 percent iron and 14.53 percent silica (Bennett and Thurston 1972). Locally enriched zones of secondary hematite occur in highly brecciated iron formation adjacent to faults that extend through the Francis Hill deposit. Analyses of hard, massive red hematite ore and soft yellow ore with quartz impurities are listed as follows:

Type	Fe	SiO ₂	S	P	Source
Hard	63.10	6.34	0.09	0.27	Goodwin (1964)
Soft	50.26	19.10	0.11	0.25	Goodwin (1964)
Hard	62.46	-	0.02	0.02	Bell (1905)

For the most part, however, the average iron content of deposits in the Kabenung Lake-Iron Lake Belt is generally estimated to be between 15 and 25 percent (Bennett and Thurston 1972). The exploitation of these low grade deposits will not likely occur without significant advances in milling technology and substantially improved market conditions.

In 1966, the Algoma Central and Hudson Bay Railway Company granted a three year working option to Acme Gas and Oil Company Limited (Files, Regional Geologist's Office, Ontario Ministry of Natural Resources, Sault Ste. Marie) covering 10 townships in the Michipicoten area. The option agreement covers Townships 32 and 33, Ranges 25 and 26 which contain most of the iron prospects and some of the more important base metal prospects in the eastern end of the Kabenung Lake Belt. The option has been renewed beyond the three year period and as of October, 1971, all properties within these townships were still held by Acme Gas and Oil. Under the terms of the agreement the findings and results of exploration by Acme Gas and Oil must be turned over to the Algoma Central Railway on the termination of the option.

Sand River Gold Mines Limited examined extensive deposits of interbedded greywacke and iron formation 5 miles (8 km) south of Mishibishu Lake and 7 miles (11 km) northwest of Point Isacor in 1957. A dip needle survey on 32 claims and 2 diamond drill holes totalling 800 feet (240 m) outlined 20 units of iron formation interbedded with greywacke units (Files, Regional Geologist's Office, Ontario Ministry of Natural Resources, Sault Ste. Marie). Most individual units of iron formation were less than 50 feet (15 m) thick. In the absence of adequate grades over suitable mining widths, further work was suspended.

Prior to the widespread use of helicopter transport and helicopter-borne geophysical equipment, large tracts of inaccessible terrain in the Mishibishu 'greenstone' belt and at the western end of the Kabenung Lake Belt remained unexplored. There is no record of mineral exploration in the area during the period between the 1890-1910 iron range surveys and the discovery of gold-bearing quartz veins north of Mishibishu Lake in 1937. The gold occurrences are related to narrow, discontinuous concordant quartz veins in a 2,000 foot (600 m) wide, east-west trending shear

zone that extends intermittently over a length of 3 miles (5 km) in altered metasediments and mafic to intermediate porphyritic metavolcanics along the north margins of the Mishibishu Lake monzonite stock. Quartz-carbonate veins containing varying amounts of pyrite, chalcopyrite, galena and gold occur in strongly sheared, silicified, carbonatized, and pyritized 'greenstones' and sediments. In 1937, Hollinger Consolidated Gold Mines Limited, Erie Canadian Mines Limited and Macassa Mines Limited explored mineralized veins along this shear zone by trenching, stripping, sampling, and assaying. Between 1946 and 1952 Bishu Mines Limited completed 10,000 feet (3,000 m) of diamond drilling on what was probably the original Macassa prospect (Bennett and Thurston 1972). In 1949-1950 Amichi Mines Limited evaluated a separate gold discovery connected with a pyrite-ankerite-bearing quartz vein in narrow, northwest-trending shear zone located about 1,000 feet (300 m) north of the northwestern corner of Mishibishu Lake (Bennett and Thurston 1972). All of the gold prospects along the northern edge of the Mishibishu Lake Stock have been inactive since 1952.

Base metals have replaced gold and iron as the prime exploration target in the Pukaskwa region during the past 10 years. Disseminated and massive base metal sulphide mineralization is mainly confined to the belts of metavolcanics and metasediments and occurs as: (1) structurally controlled copper (chalcopyrite) mineralization of the classical hydrothermal type introduced in shear zones and faults that crosscut host rock structure; and (2) concordant strata-bound copper-zinc mineralization confined more or less to one rock unit in metavolcanic-metasedimentary sequences and in sulphide facies of iron formation.

Low grade, discontinuous concentrations of massive and disseminated pyrite-chalcopyrite mineralization extend over a strike length of 5,000 feet (1,500 m) in a poorly defined zone of silicified schistose metagreywacke and mafic metavolcanics located 4 miles (6.5 km) southwest of Knife Lake in Township 32, Range 26 (Bennett and Thurston 1972). Electromagnetic and self-potential anomalies along this zone were outlined by Falconbridge Nickel Mines Limited in 1962 (Bennett and Thurston 1972). Subsequently, six drill holes totalling 2,206 feet (672 m) were drilled from 200 to 700 feet (60 to 210 m) apart over a distance of 2,500 feet (750 m) along the mineralized metagreywacke unit. Assay data and drill logs submitted for assessment work credit generally indicated low and erratic copper 'values' associated with mineralized areas of limited extent and the geophysical surveys did not significantly extend known surface showings.

Trenching, stripping, geological mapping, and electro-magnetic surveys carried out by Jonsmith Mines Limited in 1962 (Bennett and Thurston 1972) delineated a second mineralized zone located about 1 mile (2 km) northeast of the Falconbridge prospect along a contact between mafic metavolcanics to the southeast and schistose metagreywacke to the northwest (Bennett and Thurston 1972). The Jonsmith sulphide horizon is 700 feet (210 m) long, up to 50 feet (15 m) wide, strikes N50E and probably represents an extension of the Falconbridge zone. Surface channel sampling and three diamond drill holes through the zone failed to establish copper grades better than 0.5 percent over significant widths (Bennett and Thurston 1972). Both the Falconbridge (Heart Lake) deposit and the Jonsmith deposit are currently held by Acme Gas and

Oil Company Limited under the terms of their option agreement with the Algoma Central Railway.

Disseminated pyrite and chalcopyrite occur in quartz veins and silicified mafic schist in a migmatite complex located 4 miles (7 km) northeast of Point Isacor near the contact between mafic metavolcanic rocks of the Mishibishu Lake Belt and a granite pluton intruding the belt (Bennett and Thurston 1972). A north-trending, steeply dipping shear zone about 1,900 feet (570 m) long and up to 30 feet (9 m) wide was explored by Sutherland and Associates in 1965. All 14 drill holes collared at 100- to 300-foot (30 to 90 m) intervals along the shear zone intersected erratic, low-grade copper-bearing zones over short core lengths. Assay values reported by Bennett and Thurston (1972) were 0.62 and 0.45 percent copper on two grab samples and 0.31 percent copper on a crude chip sample over 20 feet (6 m). The iron formation west of Iron Lake is extensively sheared, brecciated and replaced by sphalerite, chalcopyrite and pyrite.

Geochemical maps published by the Ontario Department of Mines in 1969 (Wolfe and Wright 1969) outlined anomalously high base metal concentrations in stream sediments within an area extending 2 to 3 miles (3 to 5 km) inland from Lake Superior between Point Isacor and the mouth of the University River. Numerous weak to strong soil geochemical anomalies in Cu and Zn were encountered during follow-up exploration by Rawhide "U" Mines Limited in 1969 and 1970 on claims located about 2½ miles (4 km) west of the lower University River (Northern Miner, June 25, 1970, p.17). Many of the geochemical anomalies are coincident with elongated electromagnetic anomalies that parallel the N35W regional strike of metavolcanic and metasedimentary rocks in the area. Five diamond drill holes designed to test coincident geochemical and geophysical anomalies intersected mafic to intermediate metavolcanics containing minor pyrite, pyrrhotite and narrow zones of graphite (Files, Regional Geologist's Office, Ontario Ministry of Natural Resources, Sault Ste. Marie).

In 1970, Falconbridge Nickel Mines Limited located a large number of geophysical anomalies by airborne electromagnetic and magnetic surveys over a 48 square mile (124 km²) area in the southeastern part of the Mishibishu Lake Belt between Point Isacor and Mishibishu Lake (Bennett and Thurston 1972). One hundred and sixty-one claims were staked.

Scheelite with minor molybdenite occurs in and near the margins of quartz veins within a screen of highly deformed metaconglomerate enclosed by pale pink trondhjemite about 4½ miles (7 km) east of the mouth of the University River. Irregular quartz veins up to 25 feet (7.5 m) wide are separated by schistose conglomerate in a zone extending inland from Lake Superior for about 1,300 feet (400 m) in a N34W direction. The deposit was optioned from Louis Moyd by the Crane Company in 1952 and was evaluated by trenching, stripping, detailed mapping and 53 drill holes totalling 2,254 feet (687 m). A detailed description of the deposit is included in the report of Bennett and Thurston (1972).

In 1971, the Ontario Ministry of Natural Resources cancelled all prospecting and staking of mining claims within the area selected as the site for the Pukaskwa National Park. Within the Operation Pukaskwa map-area the Park boundary (unsurveyed) is situated at the eastern limit of the Pukaskwa River drainage basin. All mineral exploration activity is therefore forbidden in the area northwest of the Lower Pukaskwa River

(below the junction with the East Pukaskwa) and northwest of the drainage divide between the Pukaskwa and East Pukaskwa Rivers. The park boundary is shown approximately in Figure 2. The National Park area is almost wholly underlain by granitic plutonic-metamorphic terrain of low economic potential.

GEOCHEMISTRY

SAMPLING, ANALYTICAL AND DATA PROCESSING TECHNIQUES

Sample Collection and Preparation

The Operation Pukaskwa geochemistry field project was mainly concerned with the application of reconnaissance stream sediment geochemistry in the preliminary evaluation of the base metal potential of the two Archean metavolcanic-metasedimentary belts in parts of the Pukaskwa and University River basins. Samples of fine-grained, active sediment were routinely collected at intervals of 1,200 to 1,500 feet (360 to 450 m) from the channels of rivers and streams, and from rivulets flowing from springs and seeps. For the most part, sediment sampling was confined to drainage within a 400 square mile (1,100 km²) area underlain by the economically favourable assemblages of Archean metavolcanics, meta-sediments and associated intrusions. An attempt was made to maintain a uniform sample density, but this was frequently not achieved because of irregularities in the drainage network imposed by extensive lake and swamp systems, particularly in low relief regions in the northern half of the map-area. As a result of unavoidable inequalities in sample distribution, the 815 sediment samples collected provide adequate coverage of 2.0 samples per square mile in about 65 percent of the total area underlain by metavolcanics and metasediments.

In addition to sampling the finest sediment fraction for later laboratory analysis, pH measurements, water temperature data and information concerning sediment composition and stream environment were routinely recorded in a form suitable for transfer to 80 column computer cards. The sediment samples were air dried and screened at a field base camp and the -80 mesh (177 micron) sieve fraction was retained for chemical analysis.

In connection with the regional survey of drainage geochemistry, specimens of unweathered bedrock were collected systematically at widespread intervals (1 to 2 miles; 1.6 to 3.2 km) to determine the large scale features of Cu, Zn, Ni, Co, and Mn variability within and between the major rock units of the Pukaskwa region. Subject to certain practical limitations governed by factors of cost and accessibility, samples of representative bedrock were collected at more or less evenly spaced, but randomly distributed sites in the Kabenung Lake and Mishibishu Lake Belts with less rigid sample control in the intervening areas of granitic terrain. Bedrock sample locations are shown in Figure 4. Each site represents a single representative specimen of the most common rock type.

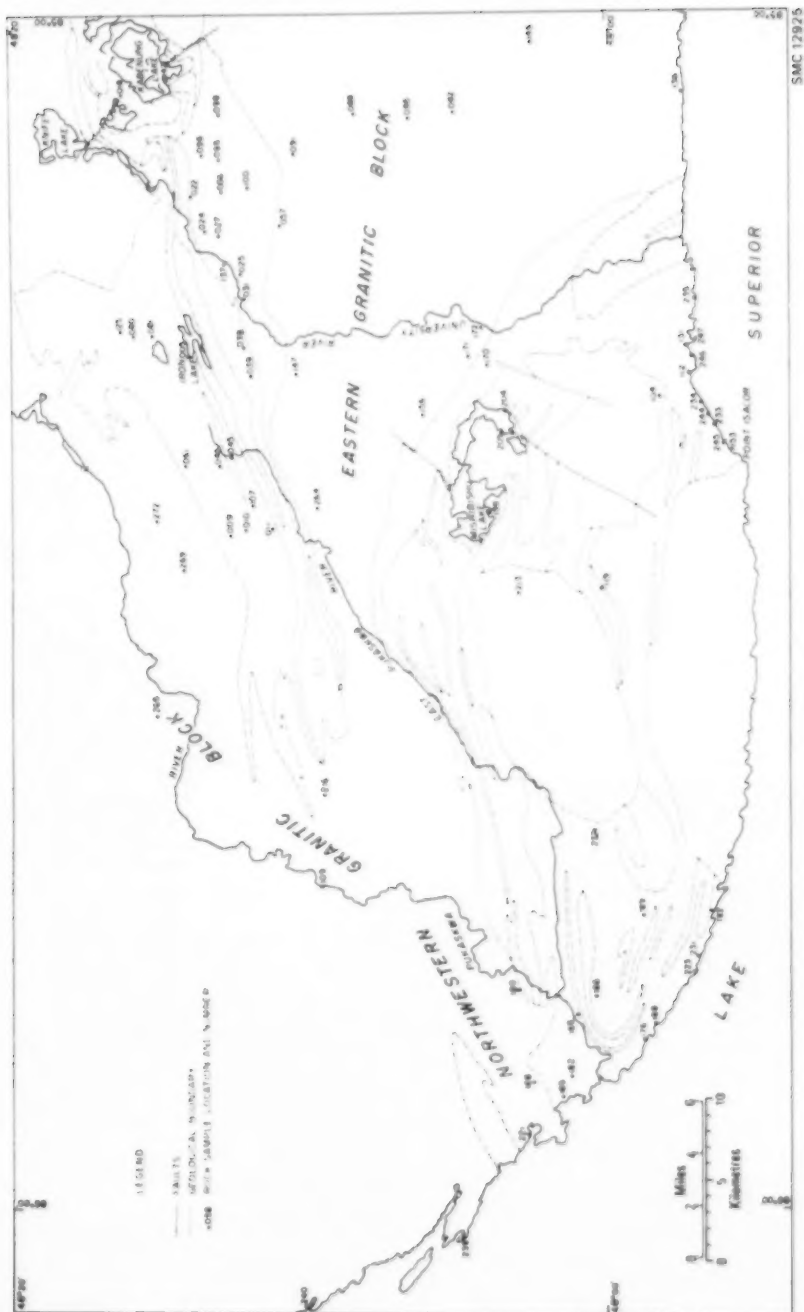


Figure 4 - Location of chemically analysed rock samples in the Pukaskwa area.

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These randomly distributed specimens of bedrock were primarily used for evaluating the effects of variable bedrock geochemistry on the regional distribution of metal background in stream sediments. The main purpose of the rock sampling project was therefore to establish gross regional patterns of metal variation in bedrock in order to compare these patterns with similar distributions encountered in surficial deposits derived largely from glacially transported material. Although a random sampling pattern is appropriate for this purpose, it lacks the necessary rigorous geological and stratigraphic control required for serious petrochemical study of volcanic sequences. It was nevertheless considered that significant new information concerning: (1) the chemical nature of Archean volcanism in the Pukaskwa area; and (2) the major element variability in granitic plutonic rocks, might emerge from total rock chemical analyses of selected groups of rock specimens. For this reason, a selection of 77 (50 metavolcanics and 27 granitic rocks) of the 292 bedrock samples collected in the Pukaskwa area was submitted for total rock analysis of major and minor constituents.

After retention of a small chip for thin sectioning and reference, unweathered rock specimens weighing 1 to 2 pounds (450 to 900 g) were successively passed through a jaw crusher and a cone crusher set to deliver material of about 10 mesh (1.68 mm) size. Crushed material was mixed by riffing on paper sheets and a sample split was taken for grinding to 200 mesh (74 micron) size in a ceramic disc grinder.

Chemical Analysis

Samples of stream and spring sediment were analysed at a field base camp for cold extractable total heavy metals (cxTHM). The determination of cold extractable total heavy metals is based on the colorimetric titration of dithizone (diphenyl-thiocarbazone) with a large group of metals that includes copper, zinc, lead, nickel, cobalt and silver. Absorbed or "loosely bonded" metals at the surfaces of mineral grains and organic materials are dissolved by the addition of a dilute ammonium citrate solution to the -80 mesh (177 micron) sample. The dissolved heavy metal is then determined by reaction with a dithizone-benzene solution to form a coloured product at a pH buffered to 8.5. The volume of dithizone required to reach a grey-blue end point provides a measure of the cold extractable heavy metal content of the sample. In this report, units of dithizone volume are converted to concentration units expressed in parts per million (ppm) of zinc equivalents by application of suitable constants. Geochemical patterns of cold extractable metal concentration are attributable to hydromorphic dispersion of soluble metals or metal complexes in ground and surface waters. The cold extractable metal component of sediment samples is therefore controlled by processes of aqueous solution, transport and precipitation.

Copper, zinc, nickel, cobalt, and manganese were determined by atomic absorption spectrophotometry in the Toronto laboratories of the Minerals Research Branch, Ontario Division of Mines. The sample solutions used for atomic absorption determinations were derived from hot HNO_3 -HCl decomposition of a 0.300 gram sample followed by dilution to 15 ml with

de-ionized water. Hot HNO_3 - HCl leaching of the sample dissolves sulphide and magnetite mineral grains and the sample solution therefore contains metals extracted from the lattice structures of these minerals in addition to the loosely bonded metals associated with clay minerals and organic material. Based on a sample weight/solution volume ratio of 0.300 g/15 ml, the sensitivities (e.g. concentrations giving 1 percent absorption) achievable by the instrumental techniques used were 1 ppm Zn, 3 ppm Cu, Mn, and Co, and 4 ppm Ni in the solid sample.

Combined analytical precision and sample homogeneity were tested by paired analyses of 154 split samples selected to cover the maximum ranges of concentration observed for all 5 elements. The coefficient of variation "C" was used to estimate the analytical variability associated with the 154 duplicate determinations according to the statistical method outlined by Huff and others (1961). The coefficient of variation expresses the standard deviation of a set of data as a ratio or percentage of the mean and therefore approaches zero in value as the precision of the data increases. Absolute agreement between duplicate or replicate determinations would give a coefficient of variation equal to 0. When applied to paired observations, the coefficient of variation is calculated separately for each set of paired data (e.g. duplicate samples) and the values of C for all sets are averaged. Commonly however, analytical precision expressed as percent deviation from the mean varies with concentration across the range of the data, generally being greater at high concentrations. For this reason, high and low ranges of Zn, Cu, Co and Ni concentration have been investigated separately by averaging the coefficient of variation in each range. Average coefficients of variation for each of the elements determined are listed in Table 4. The data indicate that Mn and Zn analyses show the highest overall degree of precision followed in order of decreasing reproducibility by Cu, Ni, and Co. Zn, Cu, and Mn analyses have approximately the same precision across the range of the data but Ni and Co reproducibility decreases significantly at concentrations below 20 ppm. In general, a mean coefficient of variation of 0.10 reflects a degree of analytical precision necessary for quantitative interpretation of exploration geochemical data.

Replicate determinations for Cu, Zn, Mn, Ni, and Co on splits from two bulk standard samples of -80 mesh (177 micron) stream sediment (NBS-1 and NBS-2) are listed in Table 5. Each set of values represents a separate weighing, digestion and analysis of an individual split of the bulk sample, so that variance of the data is in part attributable to sampling as well as analytical error.

Rock samples were also analysed for Cu, Zn, Mn, Ni, and Co by routine atomic absorption procedures similar to those used in the analysis of stream sediments. A three acid complete solution procedure using HNO_3 , HCl , and HF was used to decompose 1.000 gram samples of rock powder ground to pass a 200 mesh screen. Sample solutions were diluted to 50 ml with de-ionized water. The sample weight/solution volume ratio was the same as that used for stream sediments. Detection limits are therefore the same (1 ppm Zn; 3 ppm Cu, Mn, and Co; 4 ppm Ni). Routine precision of analyses improves with decreasing grain size of the material being analysed so that finely ground (200 mesh = 74 micron) rock powders normally yield more highly precise trace metal data than the coarser -80 mesh (177 micron) stream sediments.

TABLE 4 AVERAGE COEFFICIENTS OF VARIATION (C = STANDARD DEVIATION/MEAN) USED TO EVALUATE REPRODUCIBILITY OF TRACE ELEMENT DETERMINATIONS IN PAIRED SPLITS FROM 154 SAMPLES OF -80 MESH (177 MICRON) STREAM SEDIMENTS IN THE PUKASKWA AREA.

Element	N	Average C
Zn (all samples)	154	0.07
Zn (samples containing more than 20 ppm)	139	0.06
Zn (samples containing less than 20 ppm)	15	0.08
Mn (all samples)	154	0.07
Cu (all samples)	154	0.09
Cu (samples containing more than 20 ppm)	78	0.08
Cu (samples containing less than 20 ppm)	76	0.10
Ni (all samples)	154	0.10
Ni (samples containing more than 20 ppm)	92	0.08
Ni (samples containing less than 20 ppm)	62	0.12
Co (all samples)	154	0.13
Co (samples containing more than 20 ppm)	55	0.08
Co (samples containing less than 20 ppm)	99	0.15

N = Number of duplicate pairs

TABLE 5 REPLICATE TRACE METAL DETERMINATIONS ON SPLITS FROM TWO BULK STANDARD SAMPLES OF -80 MESH STREAM SEDIMENT IN THE PUKASKWA AREA.

NBS-1						NBS-2						
ppm						ppm						
Cu	Pb	Zn	Mn	Ni	Co	Cu	Pb	Zn	Mn	Ni	Co	
2	25	58	500	17	5	13	40	416	1325	35	11	
5	40	56	516	15	9	15	56	510	1300	31	13	
8	32	57	565	12	7	17	46	143	1525	28	12	
7	10	55	600	17	4	19	45	575	1525	35	10	
4	15	55	450	13	5	17	35	550	1350	35	10	
4	25	55	460	21	5	16	30	550	1250	35	10	
2	35	55	490	15	8	16	30	500	1400	33	11	
						17	35			31	11	
						18	38			32	20	
Average	4.6	25.9	55.9	512	15.7	6.1	16.5	39.5	502	1382	32.8	12.0

The 77 samples selected for total rock analysis were routinely analysed by the so-called 'rapid-method' of silicate analysis based on the determination of eight constituents (Si, Al, total Fe, Ca, Mg, K, Ti, and Mn) by X-ray fluorescence spectroscopy, and the remaining constituents (Fe^{+2} , Na, P, S, CO_2 , and H_2O) by standard rapid chemical wet lab methods. A single fused pellet sample was used for X-ray fluorescence determinations, and quantitative results were obtained by referring the instrumental readings to working curves prepared from standards having compositions as closely related to the unknowns as possible. Each batch of samples was monitored by a series of laboratory stands, and unknown samples were regularly checked by standard wet chemical methods. Although data are incomplete, estimates of accuracy for determinations made by X-ray fluorescence procedures are comparable to those given by Maxwell (1968, p.515) for the direct pelletization X-ray emission spectrography method used by the Geological Survey of Canada. The largest absolute errors in accuracy are associated with determinations of SiO_2 , Al_2O_3 , and in some samples MgO . Although these errors may be reflected in molecular norm calculations, they are seldom large enough to significantly obscure the essential features of a petrochemical classification based on normative minerals. The rapid X-ray fluorescence method provides useful 'reconnaissance' chemical data for very large groups of samples having similar compositions in cases where the inadequacies of field sampling procedures generally do not justify the application of more rigorously accurate but time consuming methods of analysis.

Data Processing and Analysis

Major and minor element data, trace element data and field data were transferred to 80 column computer cards for electronic data processing. Most of the initial statistical evaluation of stream sediments data was undertaken by G.R. Wright in the preparation of an undergraduate thesis at the University of Toronto titled 'Statistical Analysis of Trace Metals in Stream Sediments' (Wright 1969). Subsequent calculations involving statistical analysis of stream sediment and bedrock geochemical data, classification of metavolcanics by petrochemical parameters and normative mineralogy were performed by the Geological Branch, Ontario Division of Mines, using the Ontario Government UNIVAC 1106 computer. The following computations were made:

- (1) Computation of mean coefficients of variation for Cu, Zn, Mn, Ni, and Co to obtain estimates of analytical precision for these elements using 154 paired splits of stream sediments.
- (2) Computation of arithmetic means, standard deviations, ranges, medians, and construction of histograms and cumulative frequency curves to examine the forms of distribution of untransformed Cu, Zn, Mn, Ni, Co, and c_xTHM data in stream sediments and metavolcanics, metasediments, and granitic rocks.

- (3) Computation of geometric means, standard deviations, and construction of histograms and cumulative frequency curves to examine the distributions of logarithmically transformed Cu, Zn, Mn, Ni, and Co data in stream sediments and meta-volcanics, metasediments and granitic rocks.
- (4) Computation of correlation matrices for untransformed and logarithmically transformed trace metal from stream sediments and major rock units.
- (5) Construction of moving average trend maps to outline regional background variations in trace metal distribution in -80 mesh stream sediments.
- (6) Calculation of CIPW 'cation norms' for use in petrochemical classification of Archean metavolcanics.

MAJOR-ELEMENT CHEMISTRY OF THE ARCHEAN VOLCANIC ROCKS

Chemical analyses of 50 Archean volcanic rocks collected from the Kabenung Lake and Mishibishu Lake metavolcanic-metasedimentary belts are listed by Wolfe (1972). The analyses were grouped according to SiO_2 content and were arranged in categories of basalt (less than 52 percent SiO_2), andesite (52-58 percent SiO_2), dacite (58-64 percent SiO_2), rhyodacite (64-71 percent SiO_2) and rhyolite (greater than 71 percent SiO_2) based on the simple classification used by Goodwin (1968). The average chemical compositions of these five groups are listed in Table 6 and shown side by side with similar group averages given by Goodwin (1968) which are based on 815 analyses of Archean volcanic rocks in the Superior Province of the Canadian Shield. The distribution of the Superior Province analyses among the five compositional groups reflects a tendency to over-sample the intermediate to felsic volcanic units in relation to their true areal abundance. However, the compositional distribution of the Pukaskwa analyses conforms more closely with estimates of relative areal abundances of mafic and intermediate to felsic volcanic units in the Pukaskwa area.

Except for minor differences, the Pukaskwa analyses reflect the general chemical uniformity, the low alkali content (particularly K_2O), the low TiO_2 content, and the limited range (2.4 percent) in average Al_2O_3 noted by Wilson *et al.* (1965), Baragar (1966; 1968) and Goodwin (1968) in widespread Archean volcanic sequences within the Precambrian Shield.

Archean volcanics of the Canadian Shield are normally metamorphosed to a degree that precludes classification by conventional mineralogical systems. Although it is recognized that a chemical analysis may not always be strictly definitive in terms of the original mineralogy of a volcanic rock, Irvine and Baragar (1971) have demonstrated the general usefulness of a classification designed to give chemical definition to conventional rock names by empirical use of total rock chemical data and derived normative mineralogy. Using a computer program supplied by T.N. Irvine of the Geological Survey of Canada, the Pukaskwa volcanic rocks were classified following the graphical methods outlined in the report of Irvine and Baragar (1971). Norms were calculated by computer according to the widely used CIPW conventions and expressed in "percent cation equivalents" for pur-

TABLE 6 AVERAGE CHEMICAL COMPOSITION OF PUKASKWA AREA VOLCANIC ROCKS COMPARED WITH THE AVERAGE CHEMICAL COMPOSITION OF 815 ARCHEAN VOLCANIC ROCKS IN THE SUPERIOR PROVINCE OF THE PRECAMBRIAN SHIELD.

	Basalt		Andesite		Dacite		Rhyodacite		Rhyolite	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
SiO ₂	48.7	48.9	54.1	54.7	60.3	61.5	67.6	67.3	76.0	74.3
TiO ₂	0.98	1.06	0.87	0.99	0.75	0.63	0.47	0.51	0.23	0.26
Al ₂ O ₃	14.0	14.5	14.3	15.0	15.8	15.7	14.2	14.8	13.4	12.9
Fe ₂ O ₃	3.53	2.14	2.95	2.00	1.89	1.83	1.74	1.17	0.47	0.74
FeO	9.44	9.03	6.61	7.64	5.31	4.49	2.18	3.44	0.80	2.22
MgO	6.47	6.27	5.33	4.50	3.73	2.38	2.31	1.55	0.99	0.85
CaO	9.86	8.74	8.03	6.39	5.17	4.41	3.20	3.13	1.16	1.48
MnO	0.24	0.21	0.18	0.28	0.12	0.16	0.07	0.08	0.02	0.10
N ₂ O	1.83	2.51	3.26	2.79	3.81	3.15	3.10	3.07	4.82	2.47
K ₂ O	0.20	0.45	0.55	0.55	0.64	1.16	2.65	1.40	1.13	2.10
H ₂ O	2.79	3.34	2.15	2.92	1.99	2.27	1.38	1.56	0.59	1.17
CO ₂	1.18	1.93	1.04	1.93	0.64	2.18	0.85	0.98	0.10	0.86
P ₂ O ₅	0.09	0.07*	0.15	0.12*	0.15	0.12*	0.12	0.07*	0.03	0.07*
S	0.07	-	0.02	-	0.02	-	0.01	-	0.01	-
N	29	162	10	119	5	272	4	177	2	85

(1) Average Chemical Composition of Archean Volcanic Rocks in the Pukaskwa Metavolcanic Belt.

(2) Average Chemical Composition of Archean Volcanic Rocks in the Superior Province of the Precambrian Shield (after Goodwin 1968).

N = number of analyses

* = average P₂O₅ figure based on 96 determinations only.

poses of graphical projection. Prior to calculation of the norm, the analyses were recalculated to 100 percent without H_2O or CO_2 on the assumption that the rocks were open only to the volatile components during metamorphism. In addition, the ratio of Fe_2O_3/FeO was adjusted by placing an upper limit on Fe_2O_3 governed by the equation: $\% Fe_2O_3 = \% TiO_2 + 1.5$. If Fe_2O_3 exceeded $TiO_2 + 1.5$, the 'excess' was converted to FeO leading to a more undersaturated norm. The adjustment of Fe_2O_3 content in metamorphosed volcanic rocks produces an Fe^{+2}/Fe^{+3} ratio which more closely approximates the primary pre-metamorphic composition.

Metamorphic alteration of primary chemical compositions is most evident in volcanic rocks of basaltic composition and combined $CO_2 + H_2O$ is generally regarded as the most realistic index of metamorphic or hydrothermal alteration. High levels of CO_2 and H_2O can seriously affect the values of other constituents by dilution. Although adjustments of the analytical data prior to norm calculations are designed to remedy this situation, the appearance of normative olivine and/or nepheline associated

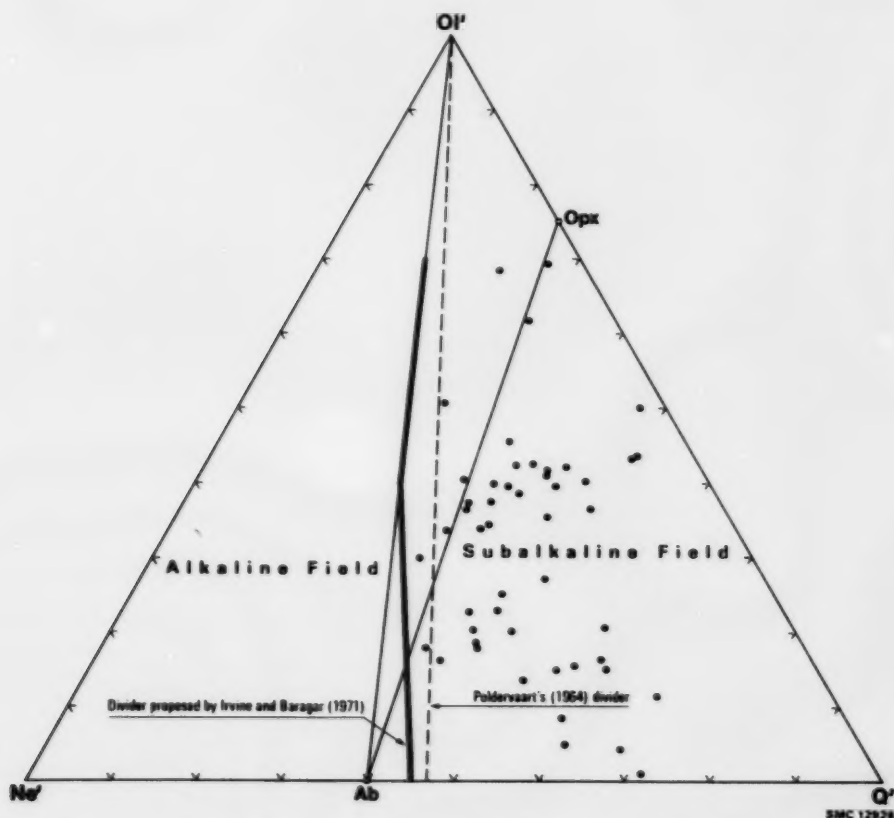


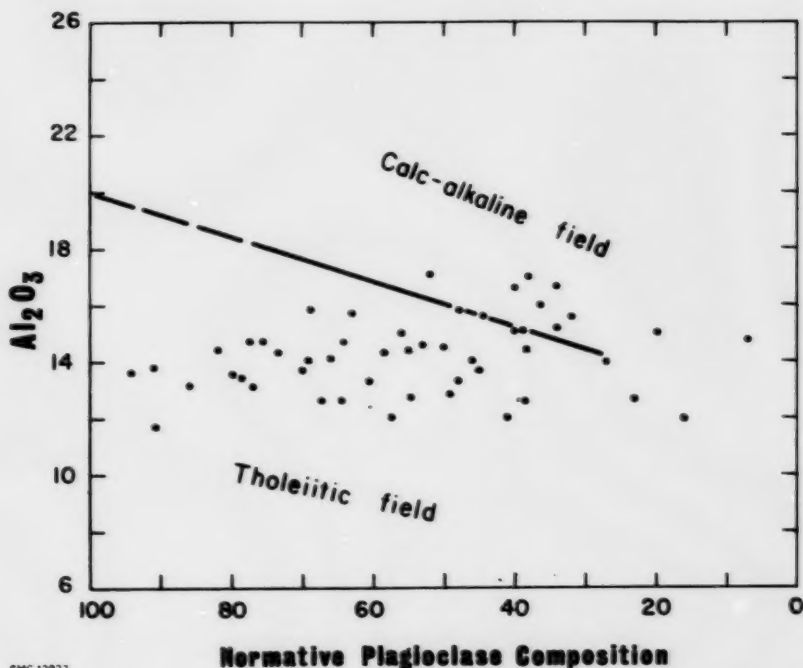
Figure 5 - O1-Ne-Q projection of normative compositions of Archean volcanic rocks in the Pukaskwa area.

with highly altered basalts containing 5-12 percent $\text{CO}_2 + \text{H}_2\text{O}$ and low SiO_2 (less than 46 percent) may reflect changes in primary bulk composition rather than a true state of primary silica undersaturation. For this reason, analyses of severely altered rocks were rejected for purposes of the chemical classification.

The Pukaskwa volcanic rocks were classified as subalkaline according to the boundary line suggested by Irvine and Baragar (1971) for the 01'-Ne'-Q' basal projection (Figure 5) of the Cpx-01-Ne-Q tetrahedron used by Yoder and Tilley (1962) to classify basaltic rocks.

Subalkaline volcanic rocks were further assigned to the tholeiitic basalt series or the calc-alkali series according to the boundary shown on the plot of normative plagioclase composition versus Al_2O_3 (Figure 6). This plot indicates the existence of both tholeiitic and calc-alkaline compositions in the Archean volcanic belts of the Pukaskwa region and confirms the widely recognized association of tholeiitic basalts with calc-alkalic andesite-dacite-rhyolite successions in Archean 'greenstone' belts of the Precambrian Shield (Wilson *et al.* 1965; Goodwin 1968; Baragar 1966, 1968).

An attempt was made to re-classify the analyses of volcanic rocks by plotting normative colour index against normative plagioclase composition in the manner suggested by Irvine and Baragar (1971). Analyses



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Figure 6 - Plot of weight percent Al_2O_3 versus normative plagioclase composition for tholeiitic and calc-alkaline volcanic rocks.

plotted in Figure 7 are designated as basalt, andesite, dacite, or rhyolite according to their silica content using the SiO_2 boundaries proposed by Goodwin (1968). It is apparent that a substantial upward revision of the silica boundaries between basalt-andesite and andesite-dacite groups would be required to make the two methods of classification conform. The new classification would eliminate the rhyodacite group, although Irvine and Baragar (1971) have suggested that the term rhyodacite might be retained for unusually potassium-rich dacites, and would define categories of basalt (less than 56 percent SiO_2), andesite (56-62 percent SiO_2), dacite (62-70 percent SiO_2), and rhyolite (greater than 70 percent SiO_2).

MAJOR-ELEMENT CHEMISTRY OF THE GRANITIC PLUTONIC ROCKS

Total rock chemical analyses of 27 granitic plutonic rocks collected from the Kabenung Lake and Mishibishu Lake Stocks and the extensive granitic terrain surrounding the two 'greenstone' belts are listed by Wolfe (1972).

The analyses were arranged in three groups on the basis of certain regularities in the distributions of silica and alkalis that seemed to be related

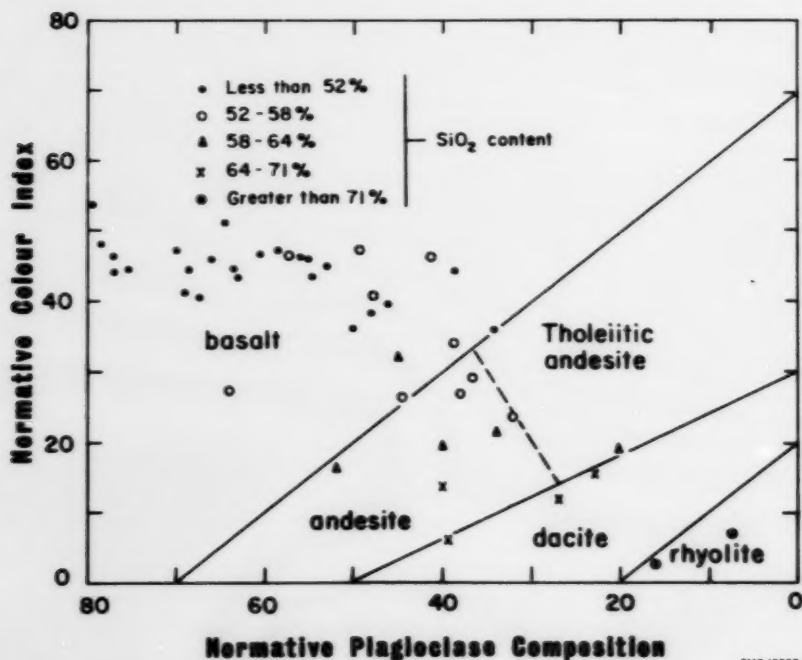


Figure 7 - Plot of normative colour index versus normative plagioclase composition for Pukaskwa volcanic rocks.

to geological occurrence and geographic distribution of the samples. The eastern granitic block is located southeast of the East Pukaskwa River between the two principal metavolcanic-metasedimentary belts (Figure 4) and is consistently depleted in potassium with respect to the northwestern granitic block and the monzonitic stocks that intrude the Archean volcanic-sedimentary belts. Many of the rocks in the eastern granitic block can be classified as trondhjemitic on the basis of their characteristically high $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios. In contrast, the average $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio of samples from granitic terrain northwest of the East Pukaskwa River is slightly less than 1.0. The circular to elliptical stocks which intrude older metavolcanics and metasediments at Kabenung Lake and Mishibishu Lake range in composition from syenite to monzonite and quartz monzonite. These discrete plutons within the Archean belts are, on the average, lower in SiO_2 and higher in combined alkalis than the extensive masses of granodiorite, quartz diorite, quartz monzonite and trondhjemite that occupy the intervening areas between the belts of volcanic and sedimentary rocks.

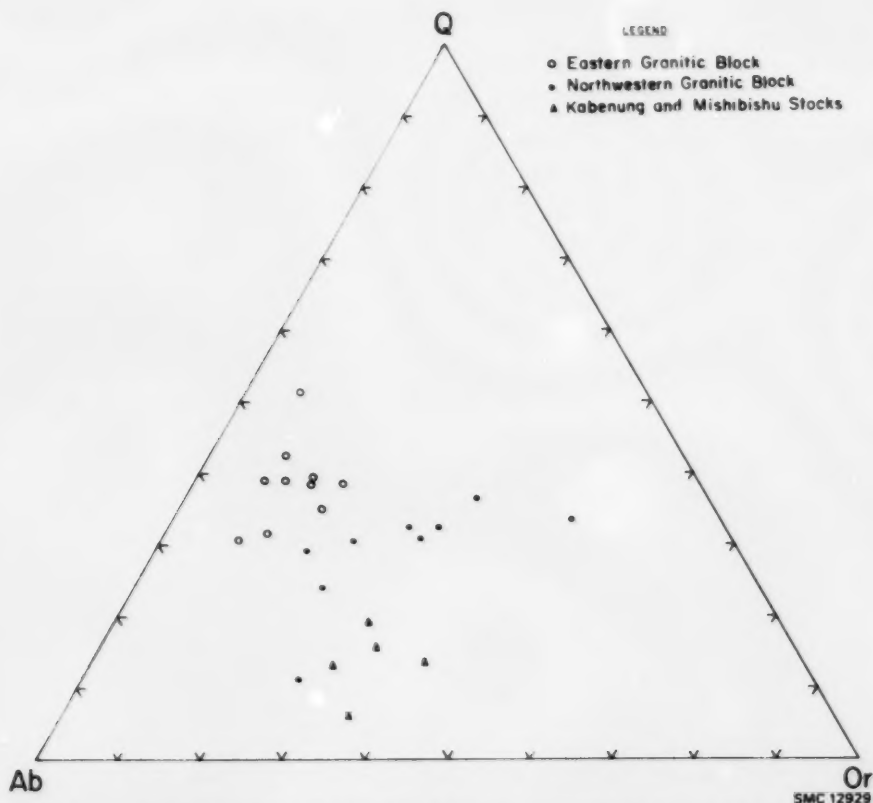


Figure 8 - Plot of normative Quartz-Albite-Orthoclase compositions for granitic rocks of the Pukaskwa area.

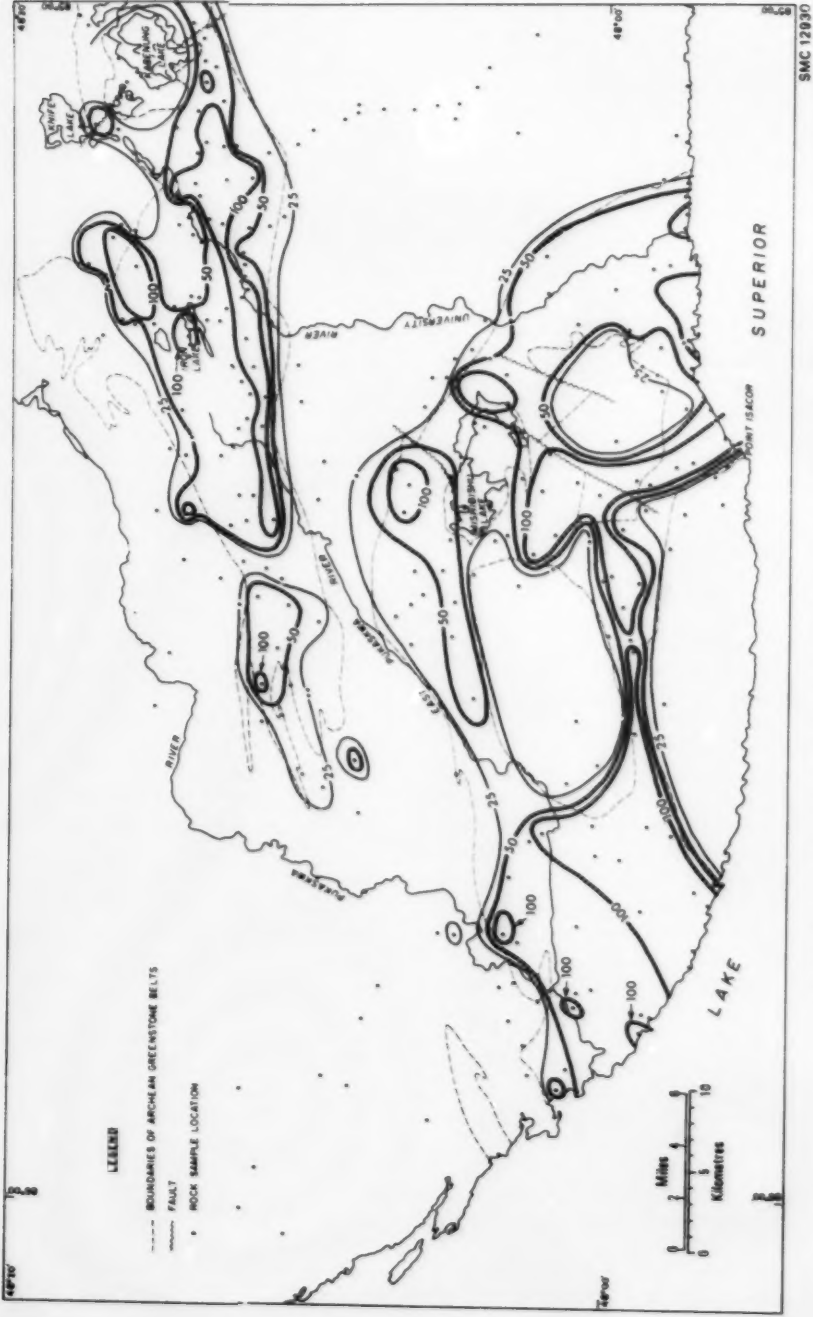
Limited analyses appear to indicate the existence of major regional variations in $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios of granitic rocks in the Pukaskwa region. The major variations in silica and alkalis among groups of samples are illustrated by the normative quartz-albite-orthoclase ratios plotted in Figure 8. The reasons for these variations are not yet clear and further sampling and analysis would be required to confirm the statistical validity of these observations.

TRACE METAL DISTRIBUTION AND DISPERSION IN ROCKS AND STREAM SEDIMENTS

Average trace metal abundances (in ppm) are: Ni-117, Cu-73, Zn-95, Co-37, and Mn-1300 in 121 Archean metavolcanics; Ni-67, Cu-44, Zn-75, Co-23, and Mn-815 in 63 Archean metasediments; Ni-23, Cu-13, Zn-50, Co-18, and Mn-322 in 104 granitic plutonic rocks. These data indicate that all metals analysed are substantially higher in the metavolcanics and metasediments than in the granitic rocks. For this reason, patterns of Cu, Ni, Zn, and Mn distribution in bedrock (Figures 9-12) showing broad features of metal variability at the regional level, all outline, more or less distinctly, the two major Archean 'greenstone' belts. Thick sequences of tholeiitic basalts are particularly well defined by the copper and nickel distribution patterns. Compared to other formations, the tholeiitic basalts have consistently high copper and nickel contents. The boundaries of the meta-volcanic-metasedimentary belts are clearly delineated by the 25 ppm nickel contour. The maps shown in Figures 9-12 outline major high contrast geochemical domains at the regional scale and form a basis for relating geochemical background variations in bedrock to those in transported Pleistocene cover.

Metal populations in the major bedrock units show evidence of strong skewness toward high concentrations and are approximated by log normal distributions. Computerized statistical treatment of the geochemical data is therefore based on logarithmically transformed data. Metal concentration frequency histograms for granitic rocks, metavolcanics, and stream sediments are shown in Figure 13. Nickel, copper, manganese (and to a lesser extent zinc) abundances in granitic and volcanic bedrock formations show strong, and statistically certain, differences. In comparison, metal abundances in stream sediments form single homogeneous distributions (Zn and Mn), or show only a weak bimodal tendency to reflect the two high contrast primary sources (Ni and Cu). The tendency toward a single homogeneous background population in stream sediments derived mainly from transported overburden resting on high contrast bedrock formations is interpreted as a reflection of mechanical mixing and homogenization by glacial processes. Secondary processes of aqueous transport and precipitation in the surface environment tend to further obscure the relationships between bedrock and stream sediment trace element chemistry.

Standard statistical parameters that describe the distributions of Cu, Pb, Zn, Ni, Co, Mn, and cold extractable total heavy metals (cxTHM) in the stream sediments of the Pukaskwa region are given in Table 7. The arithmetic mean ($\bar{X}$), geometric mean (G), and median (M) are measures of central tendency, and the range (R) and standard deviation (S) indicate the



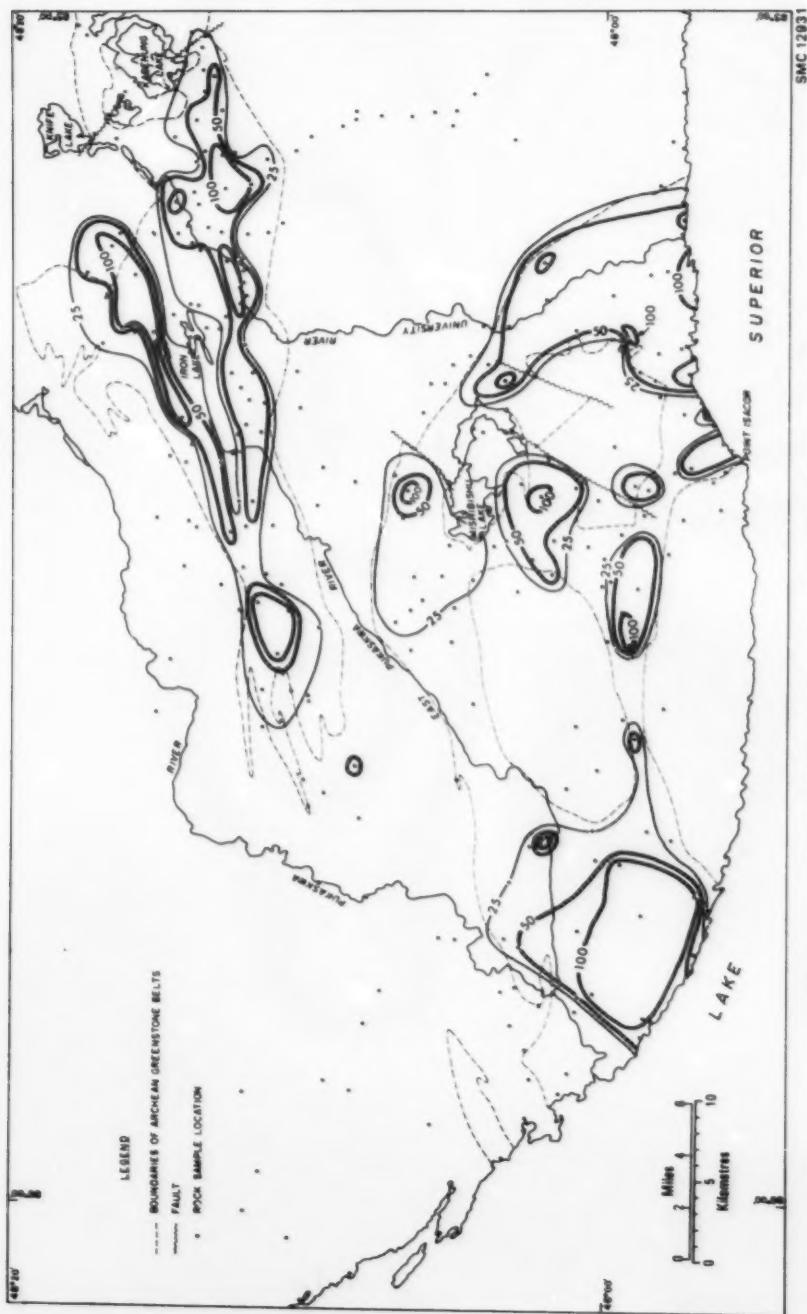


Figure 10 - Regional distribution of copper in bedrock in the Pukaskwa area.

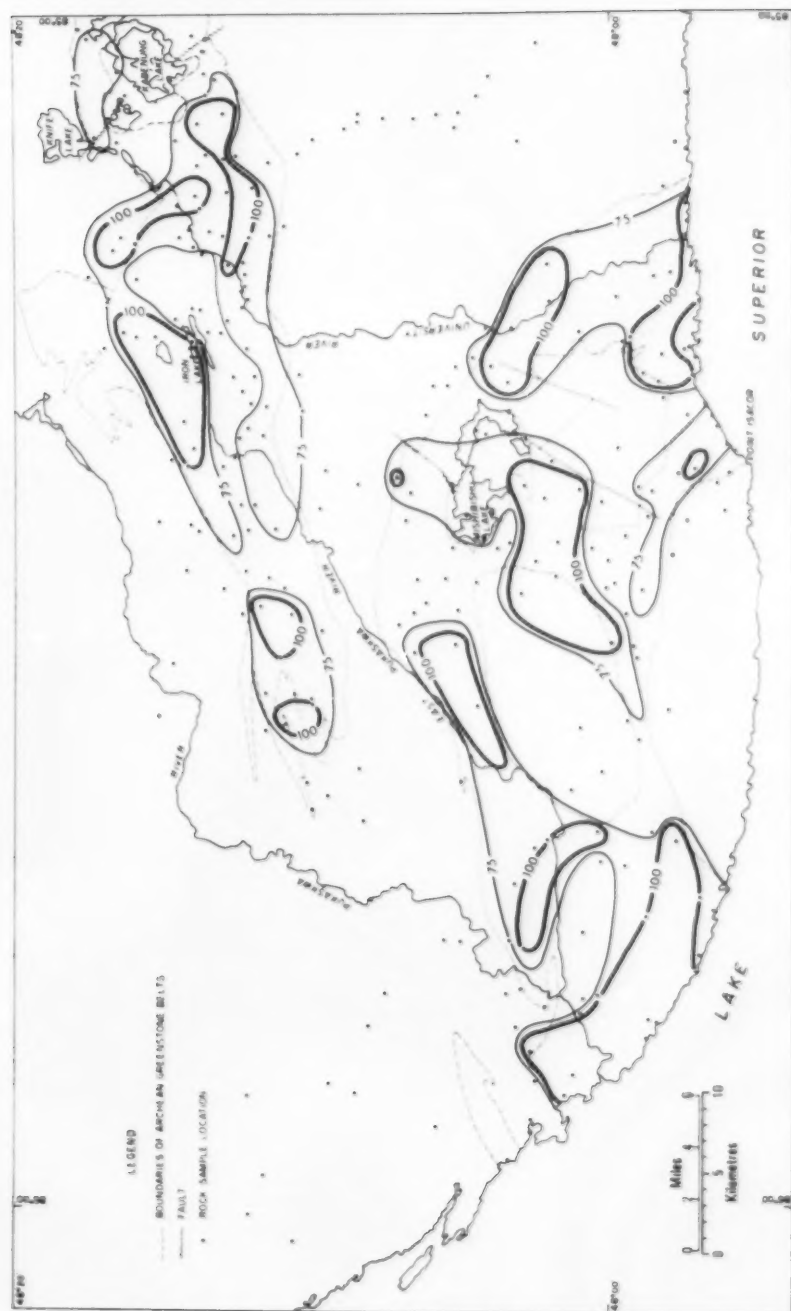


Figure 11 - Regional distribution of zinc in bedrock in the Pukaskwa area.

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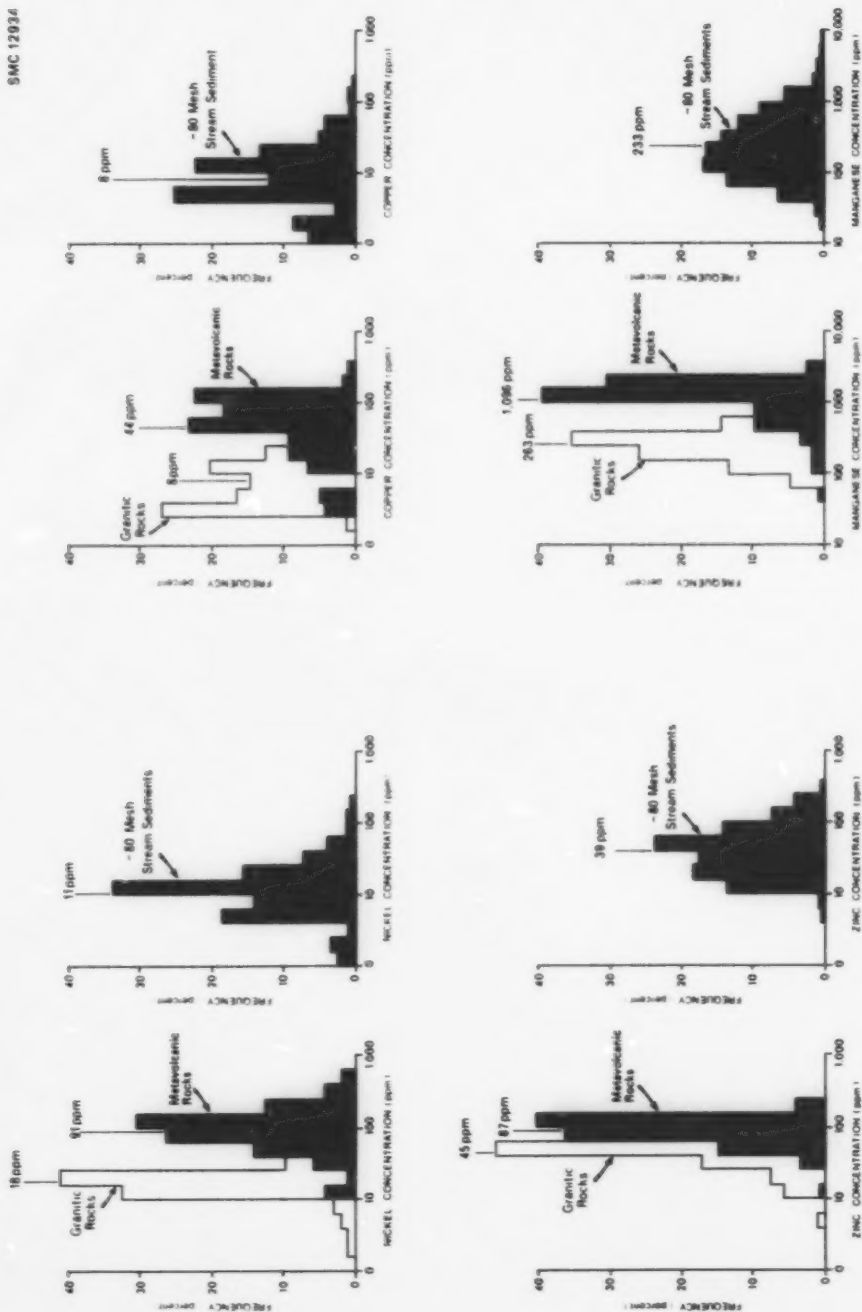


Figure 13 - Distributions of Ni, Cu, Zn, and Mn frequency in granitic rocks, metavolcanics and stream sediments in the Pukaskwa area.

TABLE 7 | STATISTICAL DATA SHOWING THE DISTRIBUTION OF METALS IN THE-80 MESH (177 MICRON) FRACTION OF STREAM SEDIMENTS FROM THE PUKASKWA AREA.

Metal in parts per million (ppm)	Cu	Pb	Zn	Ni	Co	Mn	CaTHM
Number of Samples	N	814	814	814	814	814	740
Range	R	1-186	5-340	1-198	1-50	20-6,400	0-40
Median	M	8	39	10	6	205	2
Arithmetic Mean	X	13	52	15	9	413	4
Logarithmic Mean	X _L	.90169	1.15972	1.03251	.76373	2.36658	.41732
Geometric Mean	G	8	14	11	6	233	3
Standard Deviation	S _L	.43129	.42052	.35882	.40326	.44409	.35204
X _L + S _L		1.33298	1.58024	1.39133	1.16699	2.81067	.76936
		22*	38*	25*	15*	647*	5.88*
X _L + 2S _L		1.76427	2.00076	1.75015	1.57025	3.25476	1.12140
		58*	100*	56*	37*	1,798*	13.2*
X _L + 3S _L		2.19556	2.42129	2.10897	1.97350	3.69885	1.47344
		157*	264*	129*	94*	4,999*	29.75*

* antilogarithms

$X_L = \frac{\sum \log X}{N}$ (Logarithms to base 10 used throughout)

S_L = standard deviation calculated on logarithmically transformed data

degree of spread or variability of the metal concentrations. Previous work (Wolfe and Wright 1969; Wright 1969) demonstrated that concentration frequency distributions for all metals show moderate to extreme positive skewness and that cumulative frequency curves approximated straight lines when plotted logarithmically. These features suggest that stream sediment metal populations are more or less approximated by log normal distributions. Consequently, the means ($\bar{X}$) and standard deviations (S) have been calculated on the logarithmically transformed metal concentration data. Deviations from the mean are expressed as ($\bar{X}_L + S_L$), ($\bar{X}_L + 2S_L$), and ($\bar{X}_L + 3S_L$), representing three levels above which 15.9, 2.3, and 0.14 percent respectively, of the individual concentrations will lie (assuming that the logarithms of the concentrations are normally distributed).

Regional stream sediment geochemical patterns are depicted by regional trend maps compiled by a moving average technique used to smooth out extreme local variability and to minimize variation attributable to sampling error. The contoured geochemical maps (Figures 14-19) have been generated from an orthogonal grid of regularly spaced data points derived from the original irregularly spaced data by systematically moving a one-mile side square window across the map and computing the arithmetic mean metal content of all samples within the window. This average value is assigned to the center of the square, and computed averages for each metal are contoured to produce maps outlining the broad-scale trends of metal distribution within the Pukaskwa area. Trend maps of the type illustrated in Figures 14-19 are useful in delineating areas of favourable mineral potential and in relating chemical variables to aspects of the bedrock and surficial geology. In Figures 14-19, the regional patterns of metal distribution in stream sediments are superimposed on a base map showing the boundaries of the Archean metavolcanic-metasedimentary belts and the distribution of major Pleistocene features.

Regional geochemical patterns for all metals tested show broad similarities owing to the positive between-metal cross-correlations indicated in Table 8. Areas of anomalously high Ni, Zn, Co, Mn, and cxTHM are generally restricted to those parts of the Archean metavolcanic-metasedimentary belts covered by thin deposits of stony till. The patterns of Ni, Zn, and Mn (Figures 15, 17, and 18) distribution outline the southern belt reasonably well but are substantially influenced by areas of abnormally low metal background east and northwest of Mishibishu Lake and at the mouth of the Pukaskwa River. At these locations, geochemical responses to underlying metavolcanic-metasedimentary assemblages are suppressed by thick accumulations of glaciofluvial and deltaic deposits derived mainly from distant sources in granitic terrain to the north. Widespread patterns of low metal background are similarly connected with streams draining thick deposits of glaciofluvial outwash that cover a large part of the northern belt of Archean metavolcanics and metasediments. Isolated areas of higher metal content in stream sediments are invariably associated with windows in this outwash cover.

The concentrations of 'loosely-bonded' cold extractable total heavy metals in stream sediments are closely controlled by transportation and precipitation of metals from ground and surface waters. The resulting hydromorphic dispersion patterns are best developed in regions of high topographic relief where deeply incised streams intersect the bedrock

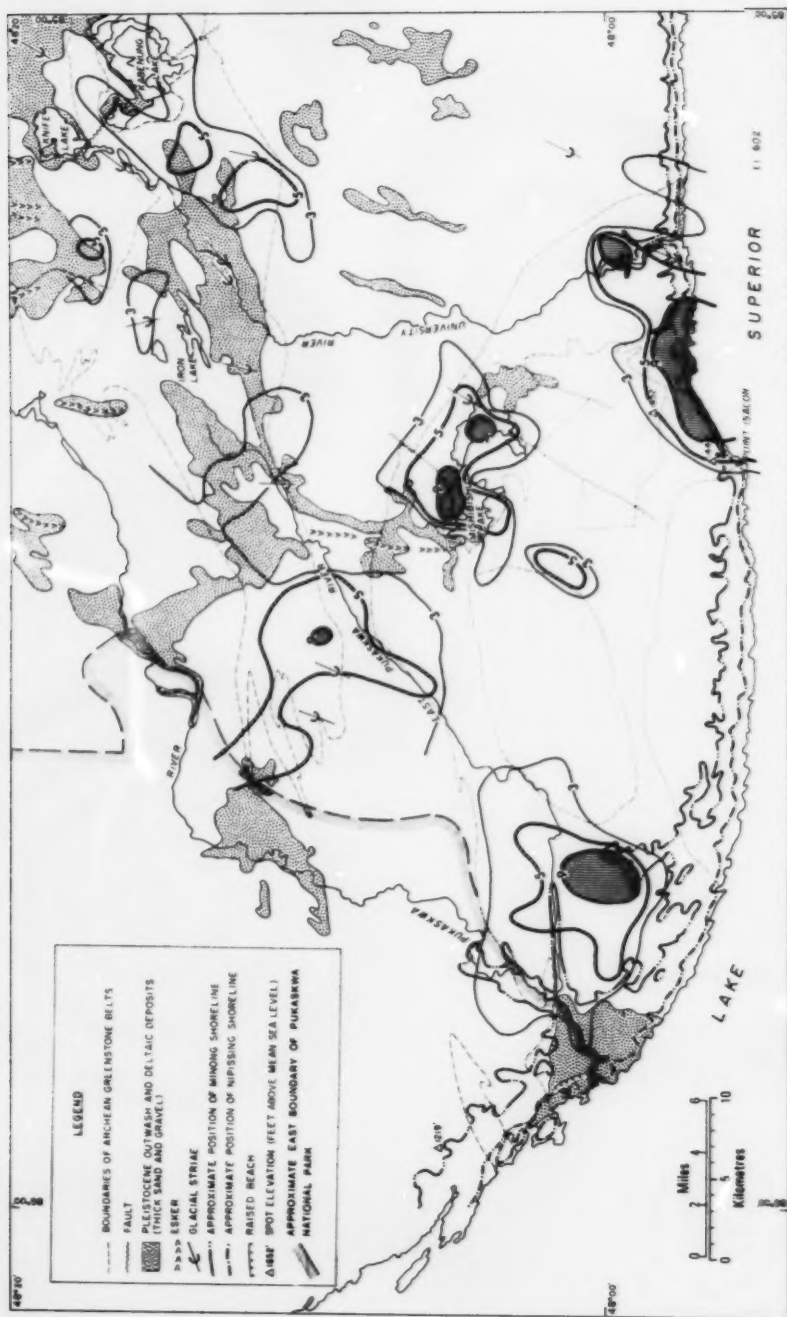
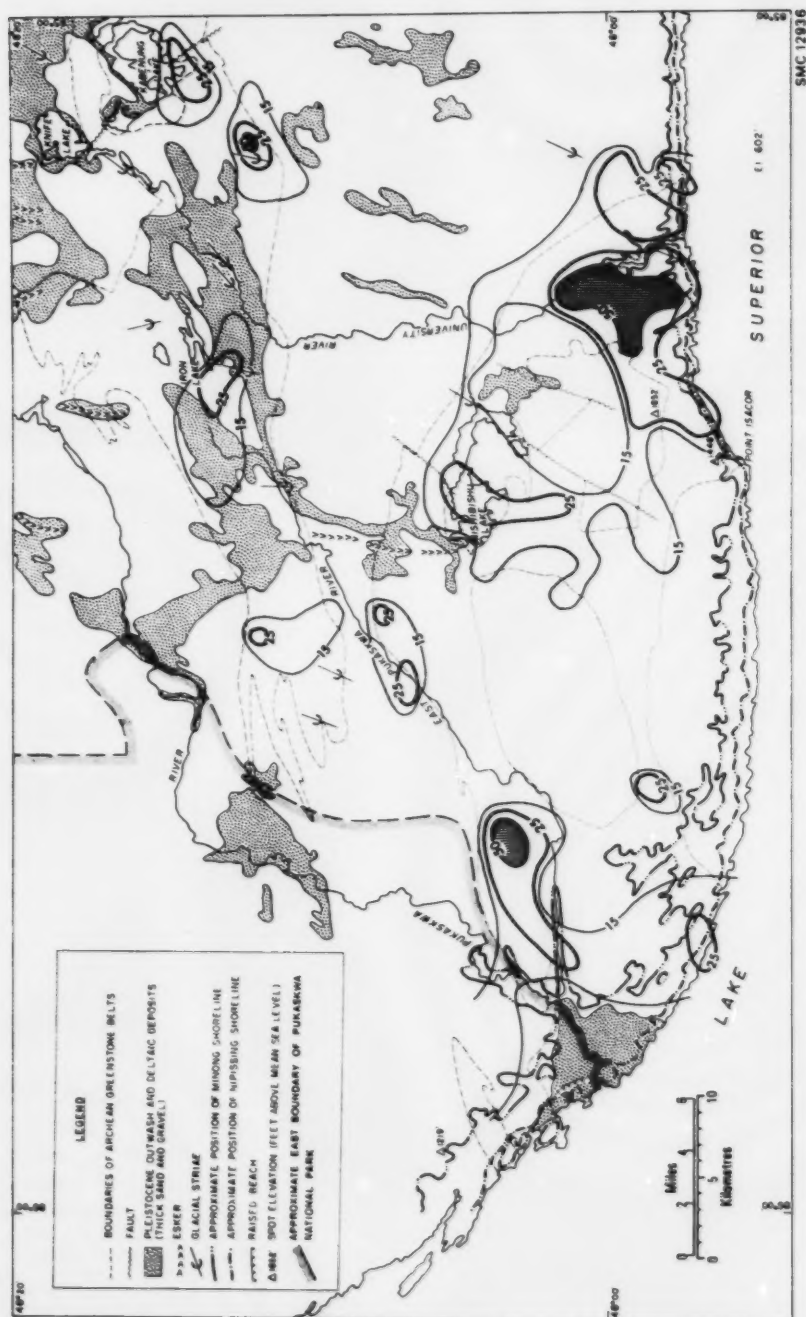


Figure 14 - Regional moving average trends of cold extractable total heavy metal distribution in -80 mesh stream sediments in the Pukaskwa area.



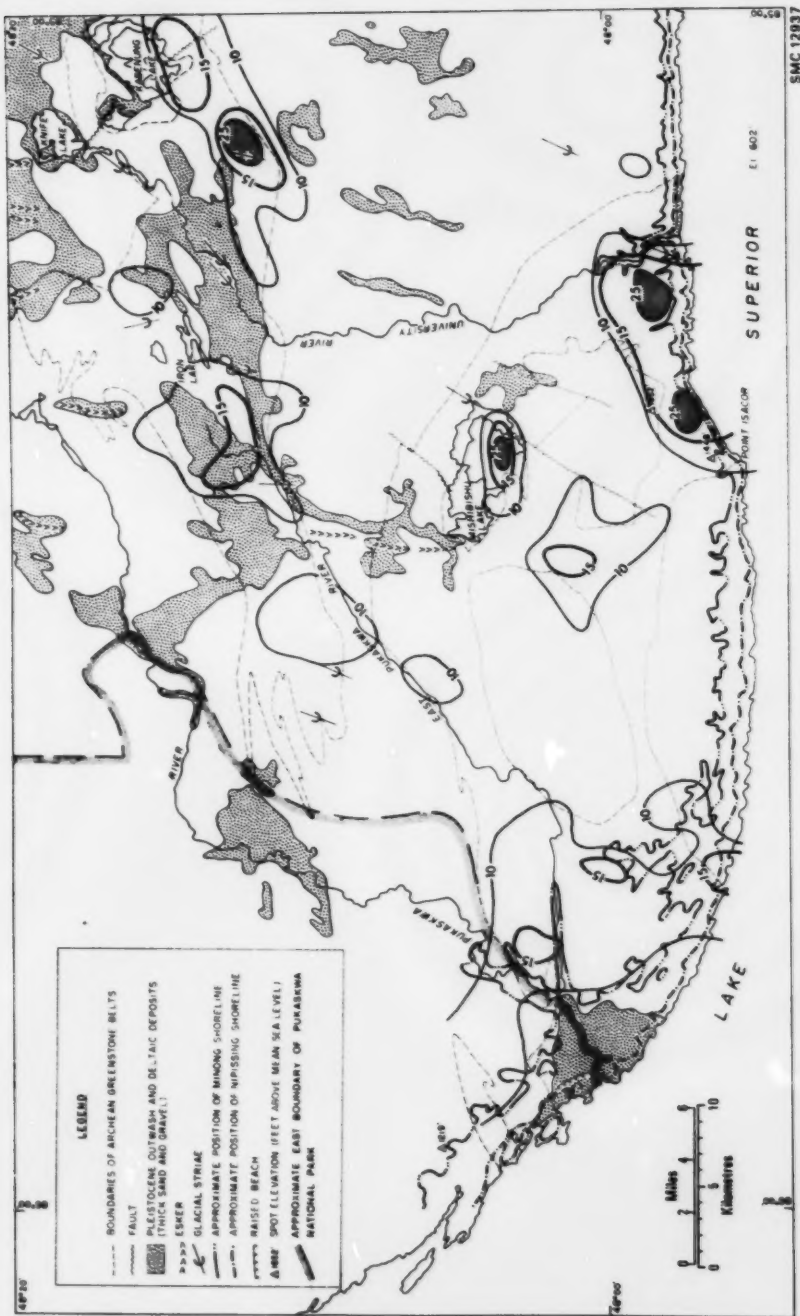


Figure 16 - Regional moving average trends of copper distribution in -80 mesh stream sediments in the Pukaskwa area.

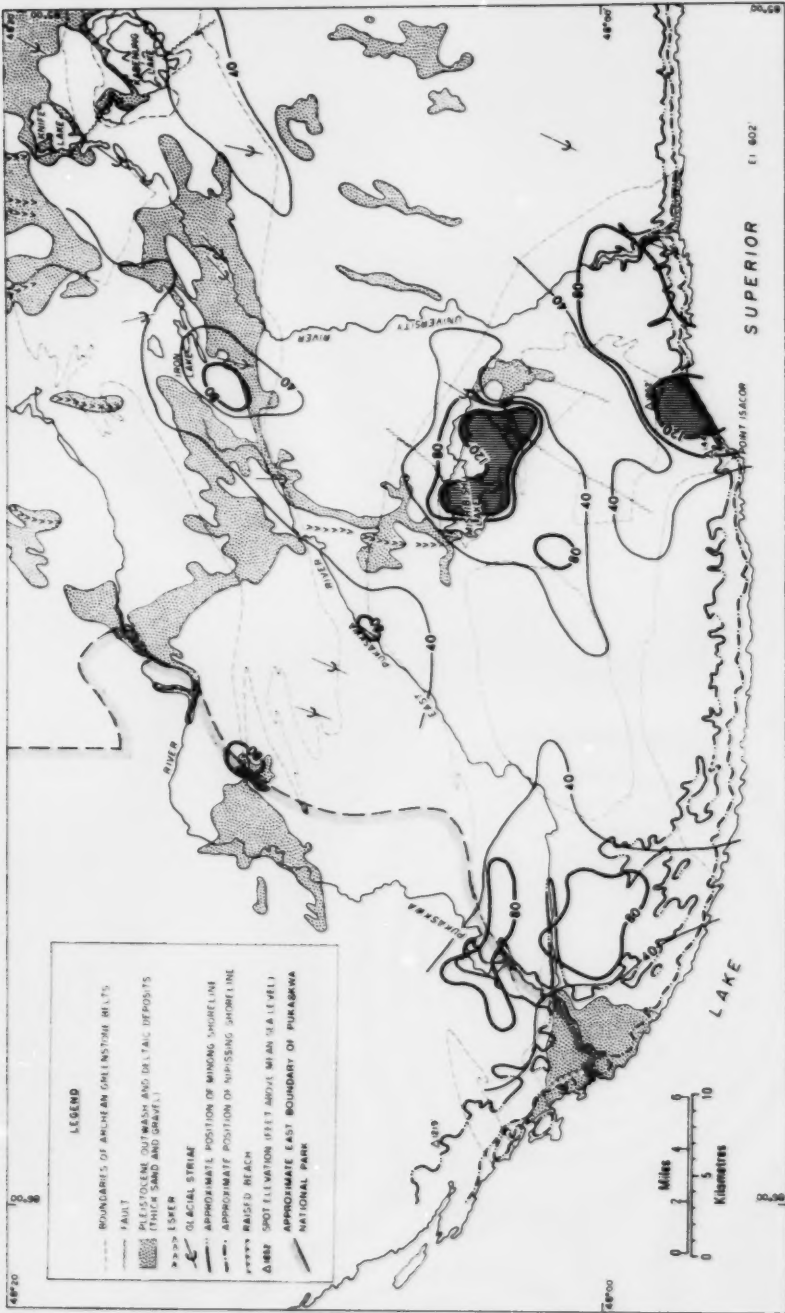


Figure 17 - Regional moving average trends of zinc distribution in -80 mesh stream sediments in the Pukaskwa area.

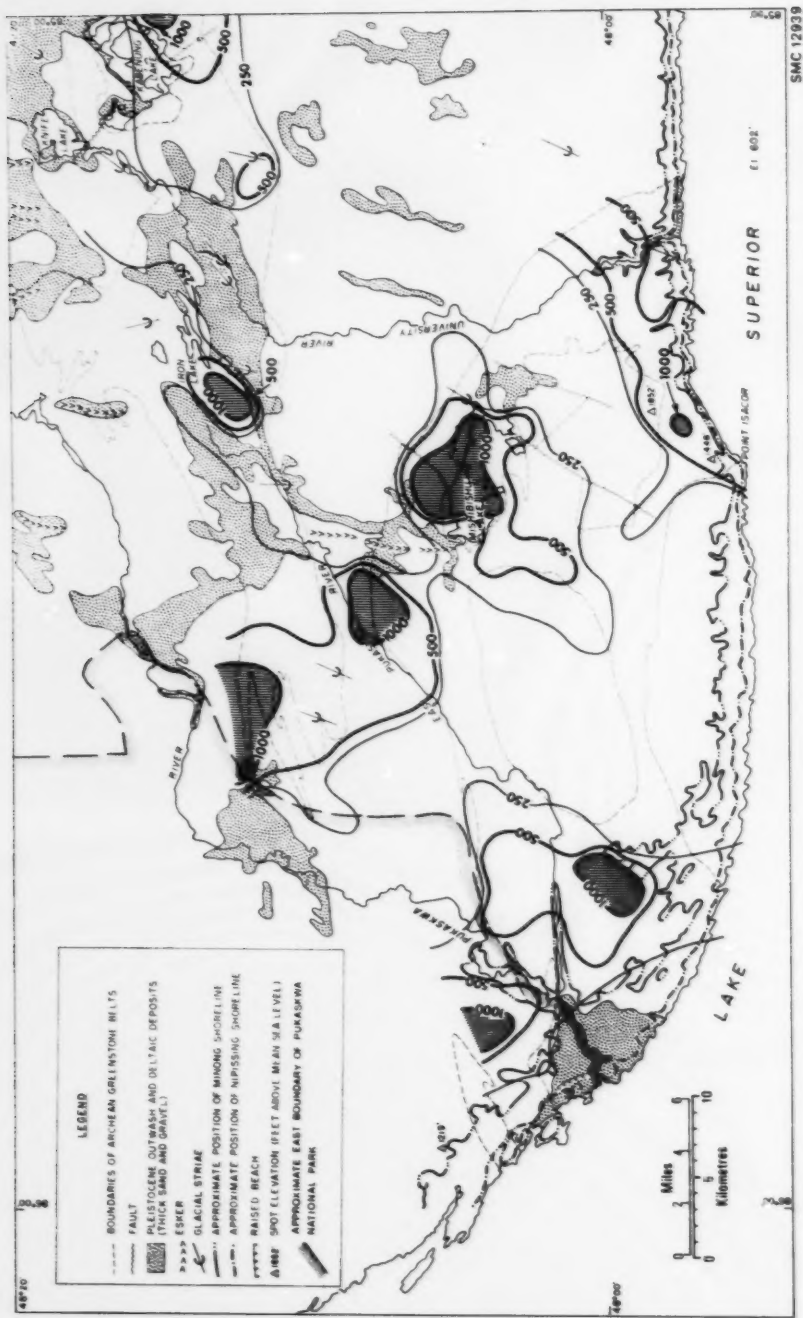


Figure 18 - Regional moving average trends of manganese distribution in -80 mesh stream sediments in the Pukaskwa area.

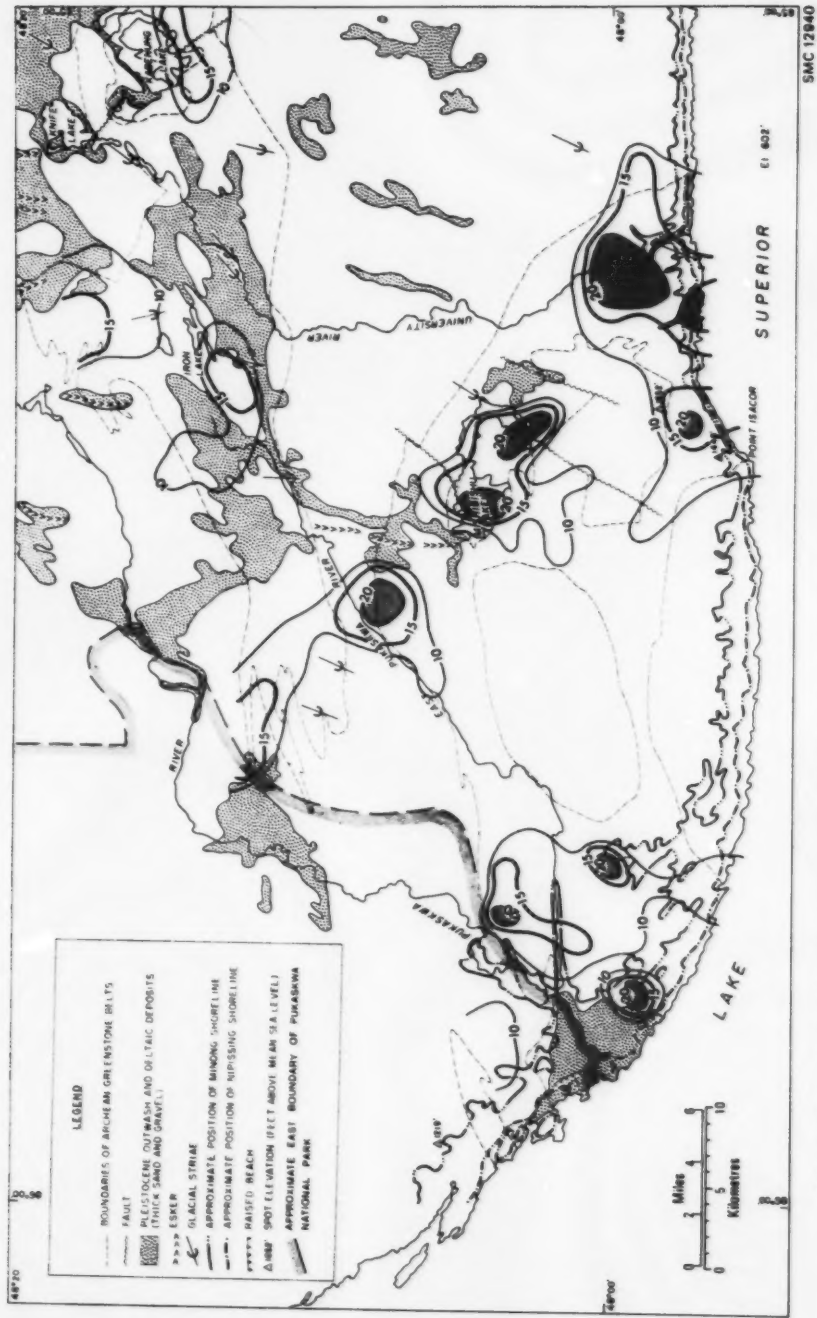


Figure 19 - Regional moving average trends of cobalt distribution in -80 mesh stream sediments in the Pukaskwa area.

TABLE 8 | METAL CORRELATION CO-EFFICIENTS FOR 815 SAMPLES OF
-80 MESH STREAM SEDIMENT FROM THE PUKASKWA AREA.

	<i>Cu</i>	<i>Zn</i>	<i>Ni</i>	<i>Co</i>	<i>Mn</i>
<i>Cu</i>	1.00				...
<i>Zn</i>	+0.70	1.00			...
<i>Ni</i>	+0.65	+0.72	1.00		...
<i>Co</i>	+0.63	+0.77	+0.69	1.00	...
<i>Mn</i>	+0.55	+0.80	+0.52	+0.72	1.00

surface, and are generally obscure in areas where low topographic relief combines with a thick cover of glacial or glaciofluvial sand and gravel deposits. Above-normal concentrations of cxTHM in drainage entering Lake Superior west of the lower University River and in the lower parts of the East Pukaskwa River Basin (Figure 14) are partly a reflection of the deeply incised topography in these regions. In comparison, stream systems draining the northern part of the area intersect the bedrock surface less frequently because of the presence of thick outwash cover over most of the Kabenung Lake Belt, resulting in lower background levels of cxTHM. Similar observations apply to Zn (because the cxTHM test is most sensitive to zinc), and streams draining the south half of the map-area account for 93 percent of all zinc 'values' exceeding 150 ppm. The patterns of cxTHM, Zn and Mn are highly correlative, and all three show strongly coincident anomalies over the quartz monzonite stock centered at Mishibishu Lake. Manganese is particularly sensitive to local variations in stream gradient, pH and (or) oxidation potential that may cause erratic Mn distribution in stream and spring sediments. An extensive area of anomalously high Zn, Cu, Ni, and cxTHM concentration in stream sediments extends 2 to 3 miles (3 to 5 km) inland from Lake Superior between Point Isacor and the mouth of the University River. Mafic metavolcanics in the area contain widespread disseminated pyrite and chalcopyrite. Several other areas of above-normal base metal concentration in drainage sediments are apparently related to occurrences of iron formation west of Iron Lake, southwest of Mishibishu Lake, southwest of Kabenung Lake, and in the western end of the Mishibishu Lake 'greenstone' belt.

Figure 20 shows the strong positive correlation between $\text{HNO}_3\text{-HCl}$ soluble Zn and Mn in stream sediments collected in the Pukaskwa region. This correlation is a general feature of most stream sediment data (Wolfe 1967, 1968; Canney 1967; Austria 1970), and a large component of the correlation is frequently attributed to Zn scavenging by, or co-precipitation with, hydrous manganese-iron oxides. Our data suggest that this correlation may result from at least three independent geological-geochemical causes. At low metal concentrations (less than 200 ppm Mn and less than 25 ppm Zn) the Zn-Mn correlations for stream sediments are probably controlled by pH-solubility relationships. Acidic stream waters play an important role in suppressing local background values for both Mn and Zn. In the

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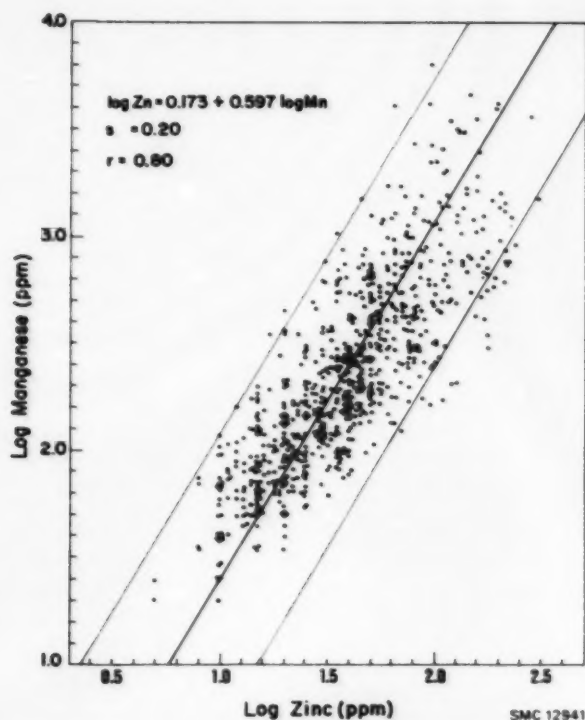


Figure 20 - Manganese-Zinc correlation in 815 samples of -80 mesh stream sediment from the Pukaskwa area.

intermediate concentration range, strong positive Zn-Mn correlation in stream sediments is probably to some extent a reflection of very similar correlation at the bedrock source. Figure 21 shows the relationship between Zn and Mn in 292 samples of bedrock from the Pukaskwa area. At extremely high concentration levels (above 4,000 ppm Mn and 150 ppm Zn) zinc values may be controlled by processes of accumulation in manganiferous precipitates in stream beds.

GEOCHEMISTRY AND GEOPHYSICS AT THE FOLLOW-UP LEVEL

Geochemical maps published by the Ontario Department of Mines in early 1969 (Wolfe and Wright 1969) indicated several specific areas of base metal potential outlined by above normal cxTHM, Cu, Zn, Ni, and Co concentrations in drainage sediments of the Pukaskwa region. In particular, a large group of high Cu, Zn, Ni, and cxTHM values was associated with streams entering Lake Superior between Point Isacor and the mouth of the University River. Maximum values of 186 ppm Cu, 340 ppm Zn and 198 ppm Ni were encountered in sediment samples collected from a broad

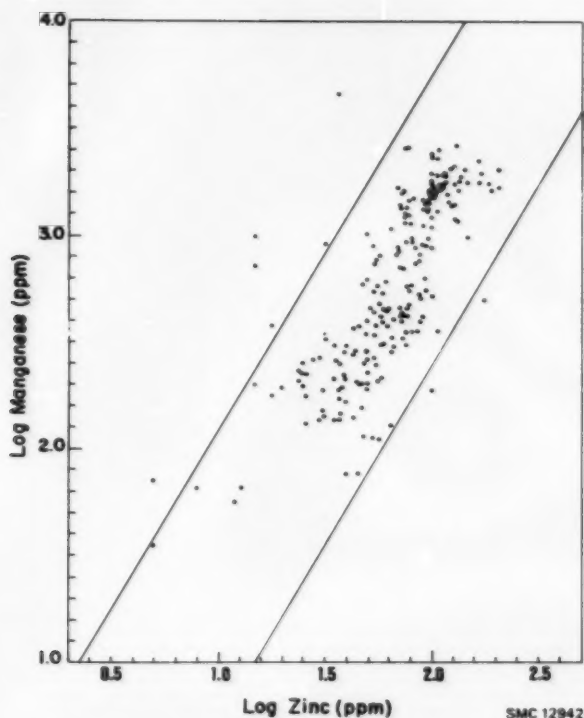


Figure 21 - Manganese-Zinc correlation in 292 samples of bed-rock from the Pukaskwa area.

area extending 2 to 3 miles (3-5 km) inland from Lake Superior. More localized anomalies up to 800 ppm Cu, 3,300 ppm Zn and 400 ppm Ni were detected by follow-up stream sediment surveys in the same area during 1969. Numerous weak to strong soil geochemical anomalies in Cu and Zn were encountered during exploration by Rawhide 'U' Mines Limited in 1969 and 1970 on 26 claims located about 2½ miles (4 km) west of the mouth of the University River (Ontario Division of Mines, Assessment File Research Office, File 63.2766, 1970). Anomalously high concentrations of Cu and Zn in soils showed some coincidence with two parallel zones of electromagnetic anomalies about 1,000 feet (305 m) apart and trending N35W parallel to the regional strike of volcanic and sedimentary rocks. Seven separate zones containing 12 anomalies were outlined along a strike distance of 2 miles (3 km) prior to diamond drilling in 1970. Figure 22 shows the pattern of hot acid extractable Cu in 'B' horizon soils in relation to the positions of electro magnetic conductors on a group of 15 claims. Copper is contoured at levels of 50, 100, 200, and 400 ppm. The area is topographically rugged and is dominated by bare outcrop and thin till cover. Soil geochemical anomalies appear to be only slightly displaced, generally in a down-sloped direction.

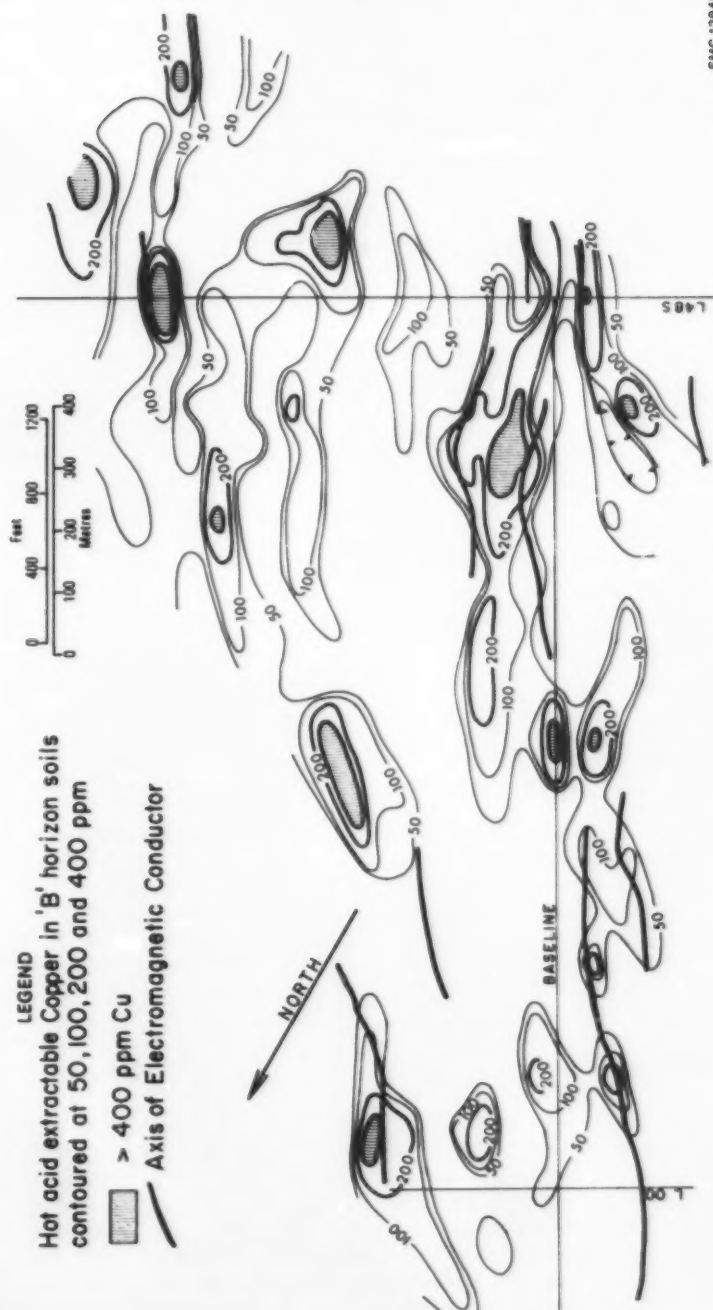


Figure 22 - Hot acid extractable copper in 'B' horizon soils in the Pukaskwa area.

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CONCLUSIONS

Conventional methods of regional and follow-up geochemical exploration can be used successfully in continentally glaciated upland regions of the Precambrian Shield. Adequate geochemical responses can be obtained in selected well-drained areas of thin till cover within the Lake Superior watershed. Interpretation of geochemical data must be based on substantial prior information concerning the nature, thickness and distribution of Pleistocene deposits in the survey area.



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